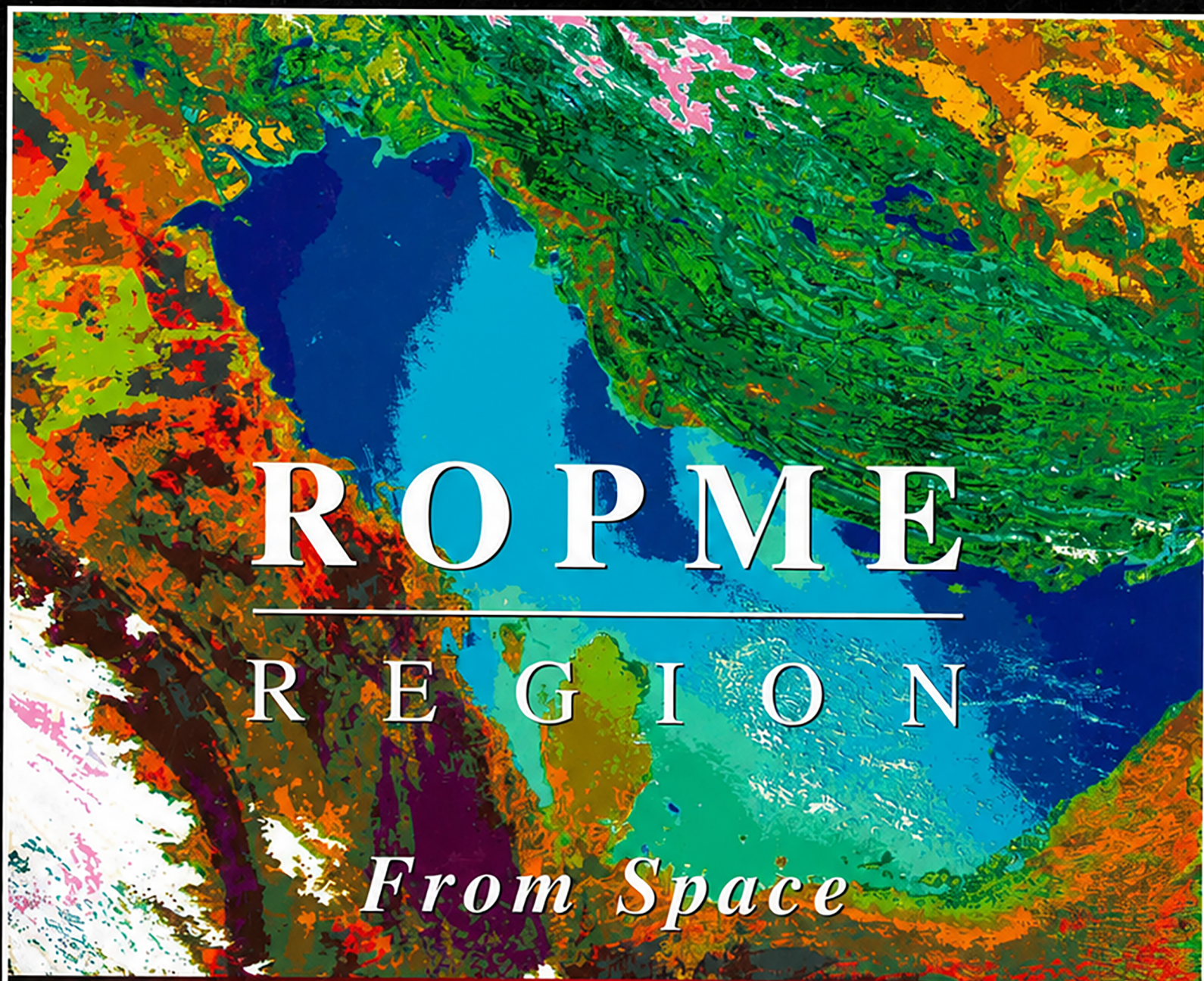
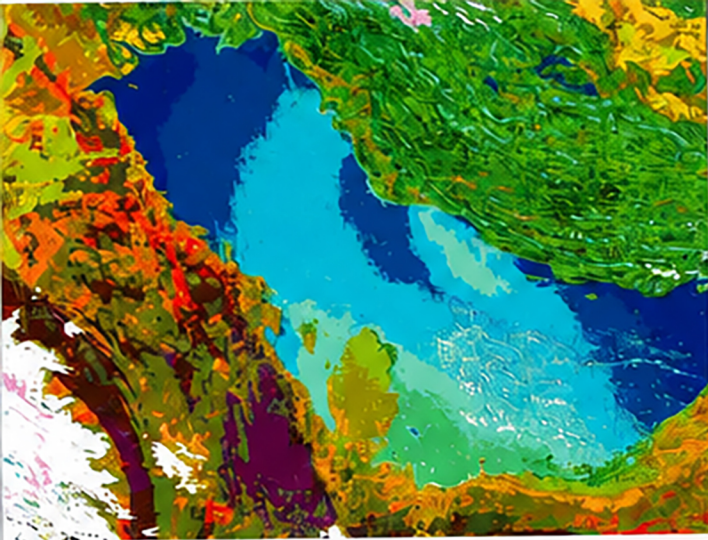






## COVER PICTURE

Classification of NOAA / AVHRR image of ROPME Sea Area. Image classification represents the various classes of natural formations in the ROPME Region. Each class identify important groups of pixels with similar spectral characteristics. The large number of classes represent the diversity of regional nature environment.

### Picture at BOTTOM-LEFT

Fragment from Infra red aerial photography from Ras Al-Zour area, South coast of Kuwait, (UNEP GIDB, 1991).

### Satellite Picture 1-Upper Left

The TERRA Project (formally known as AM-1) was responsible for the design, fabrication, test, launch, and on-orbit checkout of the instruments and spacecraft for the first EOS mission. TERRA was successfully launched on 18 December 1999. The TERRA mission is a part of NASA's Earth Sciences Enterprise (ESE).

### Satellite Picture 2-Lower Left

NOAA's Polar Orbiting Environmental Satellites Family.

### Satellite Picture 3-Upper Middle

The last in a series of Landsat satellites designed to provide repetitive global coverage of the Earth. Equipped with high resolution instruments, Landsat-7 was successfully launched on April 15, 1999. USGS, NASA.

### Satellite Picture 4-Lower Middle

The RADARSAT satellite, project of the Canadian Space Agency, marks a new achievements in earth imaging.

### Satellite Picture 5-Right

The first in a series of Landsat satellites designed to provide repetitive global coverage of the Earth - the "Earth Resources Technology Satellite - A". When operational orbit was achieved, it was designated "ERTS-1".

### Picture at BOTTOM-RIGHT

Bathymetric map of Oman coast, from Mina Raysut to Al Masirah island (Figure VIII.2 in the text).



A satellite map of the ROPME (Red Sea and Persian Gulf) region, showing the Red Sea on the left and the Persian Gulf on the right. The landmasses are depicted in shades of green and brown, indicating vegetation and terrain. The water bodies are a deep blue. The title 'ROPME' is centered over the Red Sea, and 'REGION' is centered over the Persian Gulf. Below these, the phrase 'From Space' is written in a script font.

ROPME

REGION

*From Space*



FIRST PUBLISHED IN 2000

JOINTLY BY



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REGIONAL OFFICE FOR WEST ASIA (ROWA)

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MANAMA

STATE OF BAHRAIN

E-MAIL: [UNEPROWA@BATELCO.COM.BH](mailto:UNEPROWA@BATELCO.COM.BH)

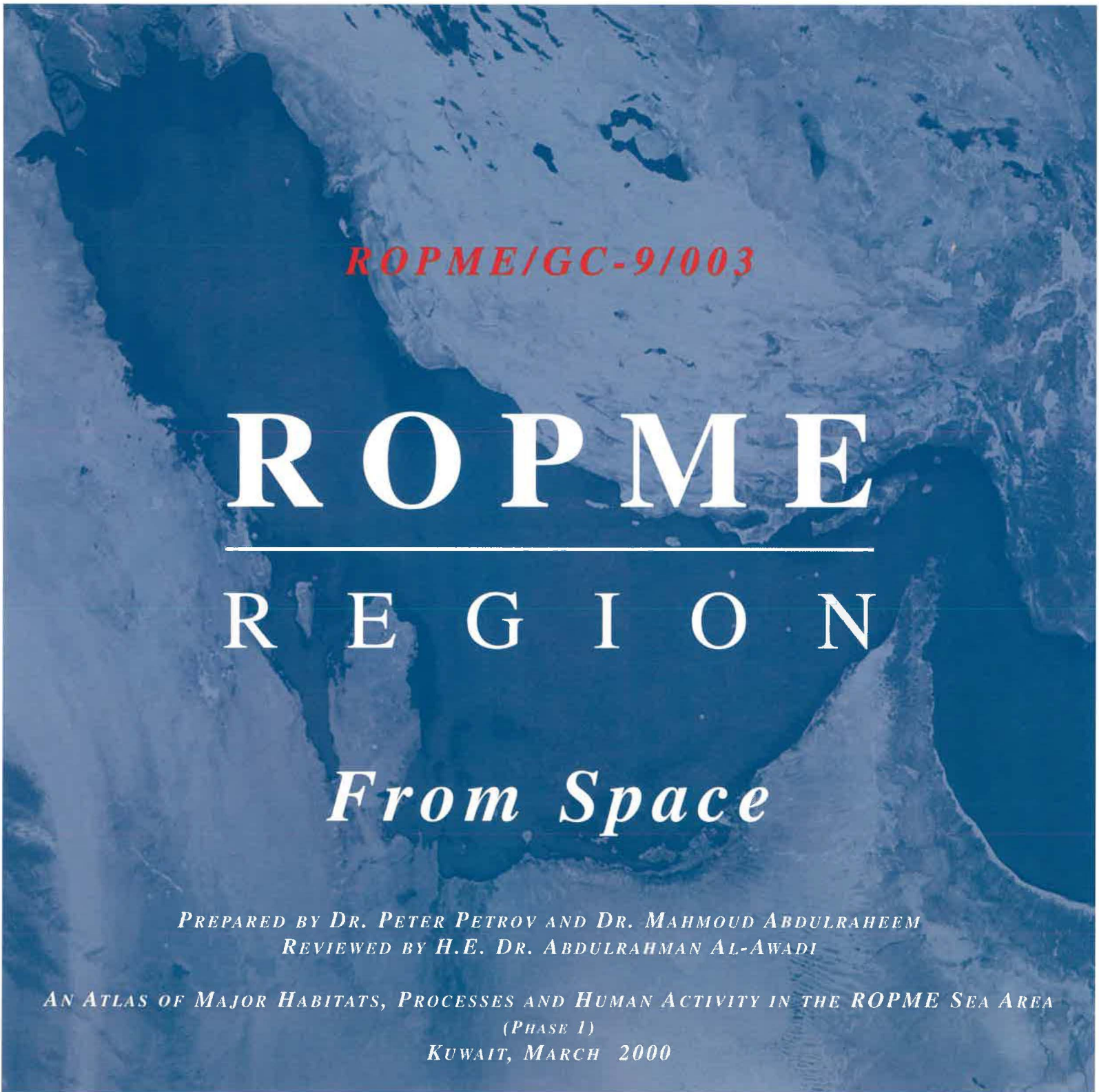
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A satellite map of the Persian Gulf region, showing the coastline of the Arabian Peninsula and the surrounding waters. The map is in shades of blue and white, with the landmasses appearing lighter and the water darker. The title 'ROPME REGION' is prominently displayed in the center, with 'From Space' below it. The reference code 'ROPME/GC-9/003' is in the top right, and the authors' names and publication details are at the bottom.

*ROPME/GC-9/003*

# ROPME

---

# REGION

*From Space*

*PREPARED BY DR. PETER PETROV AND DR. MAHMOUD ABDULRAHEEM  
REVIEWED BY H.E. DR. ABDULRAHMAN AL-AWADI*

*AN ATLAS OF MAJOR HABITATS, PROCESSES AND HUMAN ACTIVITY IN THE ROPME SEA AREA  
(PHASE I)  
KUWAIT, MARCH 2000*



# Geographical Coverage

4



(A) THE PRESENT CONVENTION SHALL APPLY TO THE SEA AREA IN THE REGION BOUNDED IN THE SOUTH BY THE FOLLOWING RHUMB LINES:

FROM RAS DHARBAT ALI ( $16^{\circ} 39' \text{N}$ ,  $53^{\circ} 3' 30'' \text{E}$ ) TO A POSITION ( $16^{\circ} 00' \text{N}$ ,  $53^{\circ} 25' \text{E}$ );

THENCE THROUGH THE FOLLOWING POSITIONS: ( $17^{\circ} 00' \text{N}$ ,  $56^{\circ} 30' \text{E}$  AND  $20^{\circ} 30' \text{N}$ ,  $60^{\circ} 00' \text{E}$ ) TO RAS AL-FASTEH ( $25^{\circ} 04' \text{N}$ ,  $61^{\circ} 25' \text{E}$ ).

HEREINAFTER REFERRED TO AS THE "SEA AREA".

-KUWAIT REGIONAL CONVENTION.



# TABLE OF CONTENTS

## FOREWARD

### I. INTRODUCTION

### II. FIFTEEN YEARS OF SPACE OBSERVATIONS OF THE ROPME REGION

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### IV. DISTRIBUTION OF VEGETATION

### V. THE MARINE ENVIRONMENT

### VI. ANTHROPOGENIC IMPACTS

### VII. STRUCTURAL ANALYSES OF PHENOMENA IN THE REGION

### VIII. GEO INFORMATION SYSTEM ANALYSIS IN THE ROPME REGION

## ABBREVIATIONS

## REFERENCES





QESHM ISLAND, MUSANDAM PENINSULA, THE STRAIT OF HORMUZ. THIS BAND COMBINATION CREATES A PSEUDO NATURAL IMPRESSION, VEGETATION APPEARS GREEN, BARE ROCK IS BROWN, TURQUOISE LIGHT GREY REGIONS ON LAND USUALLY INDICATIVE OF SABKHA CONDITIONS, LIGHT GREENISH - BLUE REPRESENTS SHALLOW AREAS.

LANDSAT 7 , 2000. RGB COLOUR COMBINATION OF BANDS 7, 4, 2.





## FOREWARD

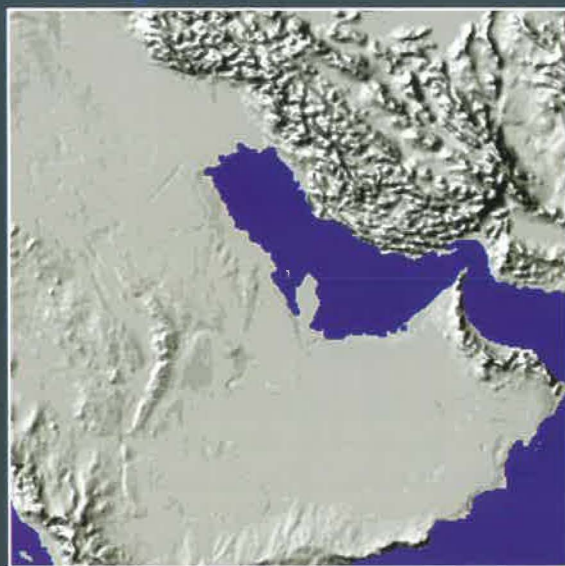
The "ROPME From Space" publication was originally designed as an atlas of the sensitive areas to oil pollution in the ROPME Sea Area in accordance with the Council Decision (CM9/23) 1996, utilizing available data at MEMAC and Member States. However, given the limited data available and the need for accurate information on the extent and history of land use patterns of the coastal and marine ecosystems, the ROPME Secretariat began exploring the possibility of using remote sensing data for this purpose. Encouraged by the amount of data available and the increasing accessibility to data bases, the Council approved the programme aiming at the establishment of a remote sensing laboratory at ROPME that would archive and analyse remote sensing data and information on the region (CM10/2) 1998. This atlas is the first consolidated product of this effort. Data and information from international databases, ROPME archived aerial photography of parts of the region and information submitted by governments and institutions from the region were all utilized in the project. The regional MOU with UNEP (1999), in which ROPME is a partner, was utilized in developing closer links with and the Regional Office for West Asia (ROWA) and the UNEP GRID centers which facilitated our efforts to obtain access to databases outside the region. We have been encouraged by the initial reaction and comments received on the first draft of the atlas. The ROPME Secretariat looks forward to the comments, amendments and suggestions of NFP's, experts and agencies to expand and further enhance the capabilities of this regional facility. We look forward to further expand the service to include near real time observation of the coastal and marine areas to provide member states to obtain accurate information on pollution and other sea surface phenomena that would enable them to take responsive actions in a timely and cost effective manner. This we hope to take place once the remote sensing receiving station is installed in the Region.

The effort exerted by the ROPME Consultant, Dr. Peter Petrov in setting up the system and in collating and interpreting the data is highly appreciated. The support provided by UNEP, from the GRID Centers and through the personal involvement of Dr. Mahmood Abdulraheem, the Regional Director of ROWA is also deeply appreciated. The input of Captain Abdulmonem Al-Janahi, Director of MEMAC, Ms. Nahida Al-Majed, and Staff of ROPME Secretariat are also acknowledged with thanks and appreciation. The guidance and constructive criticism of their Excellencies members of the Senior Executive Steering Committee-SESCOM is also appreciated.



**Dr. Abdulrahman Al-Awadi**  
Executive Secretary of ROPME





RELIEF OF THE ROPME REGION.



MAP OF ROPME MEMBER STATES AND RSA.

COASTLINE AND SHALLOW WATERS OF UAE. BARRIER ISLANDS AND ANTROPOGENIC INFLUENCE. THIS BAND COMBINATION CREATES A PSEUDO NATURAL IMPRESSION, VEGETATION APPEARS GREEN, BARE SOIL IS LIGHT YELLOW -REDDISH, TURQUOISE LIGHT GREY REGIONS ON LAND USUALLY INDICATIVE OF SABKHA CONDITIONS, LIGHT - BLUE REPRESENT SHALLOW AREAS. THERE ARE SOME CLOUDS IN WHITE, WITH SHADOW IN THE SOUTH OF THE IMAGE (UAE COAST).

LANDSAT 7 , 2000. RGB COLOUR COMBINATION OF BANDS 7, 4, 2.





# INTRODUCTION

**M**an has been attracted to the coastal zone of the ROPME Sea Area (RSA) for millennia. One of the first traces of civilization on our planet was in the northern part of the RSA. The rapid urbanisation and industrialisation of the region, and its role as a major oil producer and exporter, have frequently resulted in the degradation of marine and terrestrial natural resources, particularly in the areas under heavy anthropogenic impacts.

The complex task of environmental monitoring and assessment needs accurate and often rapid collection of detailed information about surface phenomena. This is only possible to arrange at the regional scale by means of remote sensing technology. The cost-effectiveness of satellite technology applications has increased rapidly during the past few years. This includes monitoring of coastal areas and processes. The main advantages of this technology are geographical coverage, detection capability and overcoming time, weather and image cost limitations. Over the past decades, remote sensing (RS) has demonstrated the effectiveness of orbital platforms in monitoring features and processes in the marine areas, the coastal zone and the terrestrial environment.

The RSA is characterized by unique environmental conditions. The relatively cloudless weather conditions support modern approaches (hyperspectral and polarimetry) in remote sensing. This also allows the synergetic use of optical Visible Near Infra-red (VNIR), Thermal Infra-red (TIR) and microwave (active and passive) data processing. Such large-scale applications are best utilized in the surveillance and monitoring of oil slicks.

Oil pollution is a common phenomenon along tanker routes, around offshore platforms and at oil terminals. The Integrated Project Plan for the Marine Environment, 1997 (IOC/UNESCO, ROPME), identified RS as one of the most important tools to track oil pollution over the areas of exploration of marine resources, the paths of pollutants and to assess their impacts on different marine and coastal ecosystems in the Region.

Over the past three years, ROPME has explored the potential for utilizing image-processing technology. A custom-designed, laboratory-based system for image processing procedures and the creation of a RS regional archive has been established at the ROPME Secretariat. Using examples from RSA, the efficiency of RS observations of the state of marine environment (sea-surface temperature (SST), chlorophyll concentration, turbidity, fresh water discharges, etc.), oil spills, land surface (e.g. marshes and other wetlands, vegetation cover, NDVI) and atmospheric processes from various orbital platforms is demonstrated. The examples cover the last 15 years over the entire RSA. They show the application of available sensors in optical (VIR) and microwave spectral range (SAR) in the environmental monitoring of the ROPME region. Success in developing the image processing capabilities has encouraged ROPME to develop, in cooperation with UNEP-ROWA, a proposal to establish a receiving station of satellite information and develop further the processing and archiving capabilities of the newly established system.

The dynamic nature of ROPME coastal areas requires regular observations in order to evaluate the environmental changes and their impact on natural processes, ecosystems and populations. In the case of oil spills, near and real time information is required for effective combating and law enforcement operations. The other major areas of RS applications are habitat characterization and monitoring of changes in wetlands, vegetation cover, river courses and sedimentation patterns and physical changes of beach profiles. Other processes that are of interest in the RSA and which may be monitored by RS technology include marine primary productivity, surface albedo, temperature, wind speed, atmospheric constituents, cloud cover, relative sea level changes and air-sea interactions.



# NOAA

The AVHRR (Advanced Very High Resolution Radiometer) was first launched in 1978, and performs on NOAA polar orbiting satellites. These satellites operate at an altitude of 850 km in a nearly sun-synchronous orbit, with a cross track-scanning mode of about 2,700 km, covering a range of viewing angles up to  $56^\circ$  with 1 km resolution. The AVHRR has five channels: ch1 (0.58-0.68  $\mu\text{m}$ ), ch2 (0.725-1.1  $\mu\text{m}$ ), ch3 (3.6-3.9  $\mu\text{m}$ ), ch4 (10.3-11.3  $\mu\text{m}$ ) and ch5 (11.5-12.5  $\mu\text{m}$ ). The spectral resolution and spectral ranges of the visible and near infrared bands of AVHRR makes AVHRR (ch1 and ch2) a powerful tool for monitoring green vegetation, clouds, atmospheric and water pollution. The essential influence of the atmosphere in visible and near infrared spectral range requires atmospheric correction of AVHRR data in order to determine water surface bio-optical properties, land surface type, NDVI and albedo.

# Landsat-EROS

The first remote sensing satellite images in digital form were available from the EROS Data Center's Landsat (ERTS) program (July 1972). LANDSAT/1 (ERTS), 2, 3 were launched in 1972, 1975, and 1978 and were followed by LANDSAT 4, 5 and 7. Landsat satellites perform on altitudes of 918 km (Landsats 1, 2, 3) and 705 km (Landsats 4, 5), with a 16 or 18 day repeat cycle. The sun-synchronous polar orbit of the LANDSAT allows observations of mid-latitudes at the same mid-morning time. Landsats 1, 2 and 3 contained a Return Beam Vidicon (RBV) and Multispectral Scanner (MSS). Landsats 4 and 5 contained the MSS and Thematic Mapper (TM) imaging systems and Landsat 7 the Enhanced Thematic Mapper (ETM). The RBV on Landsats 1 and 2 had three television cameras, recording green, red and near-infrared bands with 40 m ground resolution. Landsat 3 contained two RBV cameras, each with a single panchromatic band, designed for stereo images, covering  $99 \times 99$  km. In MSS the reflected light is recorded by a solid state detector that converts it to a digital electric signal. The MSS image covers an area of  $176 \times 176$  km with a resolution of 79 m. The blue light band (ch1) has better water penetration than the green light band (ch2), allowing it to generate bathymetric maps and true colour images. The spectral ranges of MSS and TM on board of LANDSAT 4 and 5 are given in Table (1.1). The advantage of TM is the combination of seven spectral channels with high spatial resolution over an area of  $176 \times 170$  km, allowing better discrimination of surface materials and monitoring of the turbulent heat exchange on the surface. The thermal band is useful in mapping shallow groundwater aquifers, springs, offshore currents, marine and land surface temperatures.



# *RadarSAT*

## *SIR-C / NASA*

*The Shuttle Imaging Radar-C, launched in 1994, is a joint effort between NASA, the German Space Agency, and the Italian Space Agency. There were two instruments on board:*

- A dual-frequency radar with L-band (23 cm) and C-band (6 cm),*
- An X-SAR with an X-band (3 cm) wavelength. The ground swath (15 - 90 km) and the resolution 10 - 200 m are variable. The incidence angles vary between 15° and 55° off nadir and flight altitude is 225 km.*

*The Polarimetric SAR data are used for RS of terrain slopes and surface relief.*

*RADARSAT is the first Canadian remote sensing satellite launched in 1995, developed by the Canadian Space Agency in co-operation with the United States. The orbit is sun-synchronous at an altitude of 798 km and an inclination of 98.6°. The orbit period is 100.7 min and the repeat cycle is 24 days. The RADARSAT SAR is a C-band (5.6 cm), operating with HH polarization, in various look angles (20° - 59°), swath width (5 - 500 km) and resolution (10 - 1000 m).*





## SCALES OF DATA USED IN THE STUDY

### REGIONAL SCALE ASSESSMENT (RESOLUTION ABOUT 1 KM PER PIXEL)

NOAA / NIMBUS SATELLITE PLATFORM, AVHRR SENSOR. LAC MODE OF OPERATION. RESOLUTION 1 KM PER PIXEL.

NIMBUS SATELLITE PLATFORM, CZCS SENSOR. LEVELS 1 AND 2.

ADMIRALTY CHARTS 1 : 750 000, 1 : 1 500 000.

### NATIONAL SCALE ASSESSMENT (RESOLUTION ABOUT FEW TENS OF METERS PER PIXEL)

RADARSAT SATELLITE PLATFORM, SAR SENSOR. LANDSAT 5 SATELLITE PLATFORM, TM SENSOR. SPACE SHUTTLE: SIR - C, VARIOUS CAMERAS.

### LOCAL SCALE (RESOLUTION ABOUT FEW METERS PER PIXEL)

UNEP GULF IMAGERY DATABASE.

### DATA FROM THE FOLLOWING SATELLITE SYSTEMS ARE USED IN THIS STUDY:

- Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration (NOAA) satellites
- Landsat Thematic Mapper (TM) / National Aeronautical and Space Administration (NASA)
- Coastal Zone Colour Scanner (CZCS), NASA, NOAA
- Space Shuttle Observations, NASA
- Radarsat, Radarsat International (RSI)
- Aerial photography, UNEP Image Database





# MAIN SATELLITE SYSTEMS

1.1

| Satellite                                                | Sensor | Spectral Range (µm)                                                                                       | Resolution (km)                                | Swath (km) | Characteristics and objectives                                                                                                             |
|----------------------------------------------------------|--------|-----------------------------------------------------------------------------------------------------------|------------------------------------------------|------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| NOAA 11-14                                               | AVHRR  | 0.58 - 0.68<br>0.725 - 1.1<br>3.55 - 3.3<br>10.5 - 11.5<br>11.5 - 12.5                                    | 1.1                                            | 3000       | Near-polar sun synchronous                                                                                                                 |
| LANDSAT 4, 5<br>NASA                                     | TM     | 0.45 - 0.52<br><br>0.52 - 0.60<br>0.63 - 0.69<br>0.76 - 0.90<br>1.55 - 1.75<br>2.08 - 2.35<br>10.4 - 12.5 | 30m X 30 m<br><br><br><br><br><br>120m X 120 m | 185        | Launched in 1986, with near-polar sun synchronous orbit, 16 days repeat cycle. Application in marine and land surface environmental study. |
| Nimbus7<br>Coastal Zone<br>Colour Scanner<br>(CZCS) NASA |        | 443 ± 10 nm<br>520 ± 10 nm<br>550 ± 10 nm<br>670 ± 10 nm<br>700 - 800 nm                                  | 0.825 X 0.825                                  | 1636       | Operated until 1986. Applied in marine and ocean study for surface chlorophyll concentration                                               |

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The aim of the study is to show the applicability of satellite remote sensing data, in optical and microwave spectral range, for operational monitoring of the surface phenomena and characterization of habitats and natural process in the RSA.

The study also aims at developing the methodology for monitoring marine environmental changes in the region to fulfil the specific needs of Member States.

TABLE 1.1(TOP): MAIN SATELLITE SYSTEMS USED TO OBTAIN DATA.

TABLE 1.2(RIGHT) : SOME PARAMETERS FOR RADARSAT.

## SATELLITE PLATFORM

## RADARSAT

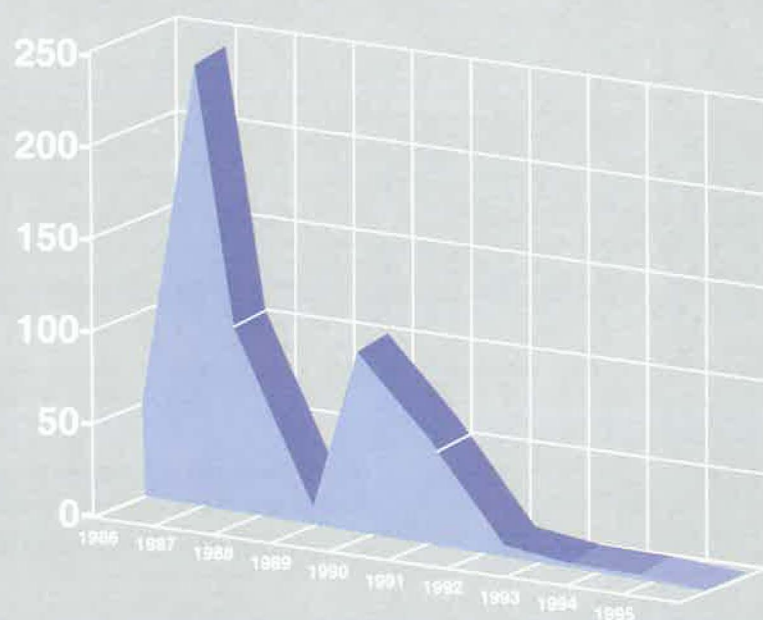
|                       |          |
|-----------------------|----------|
| Frequency             | C-Band   |
| Polarization          | HH       |
| Modes                 | Many     |
| Incidence Angle Range | 10°-50°  |
| Resolution            | 10-1000m |
| Swath Width           | 50-500km |

RadarSAT

1.2



FRAMES



YEARS  
(PERIOD FROM 9/1-12/1)

*Landsat TM images available for ROPME Region*

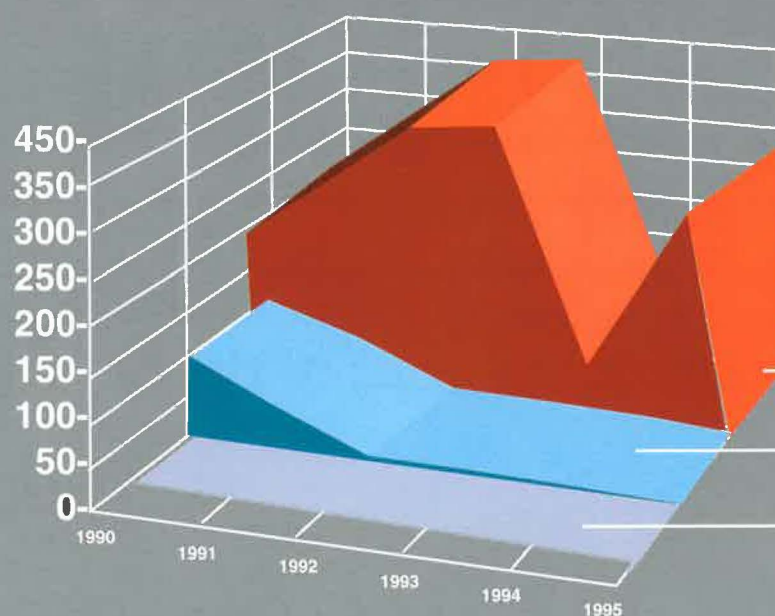
11.1

TIME DISTRIBUTION  
DIAGRAM OF LANDSAT /  
TM IMAGE DATA AVAIL-  
ABLE FOR THE ROPME REGION.  
POLYGON: N22° - N33°, E46° -  
E60°. SEASON: SEPTEMBER 1ST  
- DECEMBER 1ST

11.2

TIME DISTRIBUTION  
DIAGRAM OF REMOTE  
SENSING IMAGE DATA  
AVAILABLE FOR THE ROPME  
REGION. POLYGON: N22° -  
N33°, E46° - E60°. COVERING  
THE INNER RSA PLUS OUTER  
PART UP TO MASIRAH ISLAND.  
SEASON: SEPTEMBER 1ST -  
DECEMBER 1ST.

FRAGMENTS



YEARS  
(PERIOD FROM 9/1-12/1)

AVHRR

Landsat/TM

Landsat/MSS



## II. FIFTEEN YEARS OF SPACE OBSERVATIONS OF THE ROPME REGION

**T**he available archives of RS data contain a large amount of material related to the RSA. The main source of RS data available for the Region is from the NOAA / AVHRR sensor. The images shown in Fig II.3 and II.4 from NOAA family satellites show the ROPME Sea Area as seen from the AVHRR sensor, Band 2 (raw data with sampling rate  $\frac{1}{4}$ , after JPEG Q75 compression/decompression) during daytime. The location of the RSA differs from image to image, depending on the orbital parameters. Resolution in the image frame depends on allocation of area in the NOAA / AVHRR frame. The maximum resolution is in the middle of frame. The set of images clearly show the main physiographic features of the Region such as the Zagros Mountains in the east, the arid areas of the Arabian Peninsula in the west, the southern Mesopotamia Marshes in the North, and the Gulf of Oman in the South. These sub-regions have their own unique ecological features and associated habitats and populations.

The images also show the cloudless sea surface of the RSA. During the past 15 years, isolated patches of clouds have been seen over the coast of the RSA from time to time. Sandstorms and other phenomena related to the interaction of the atmosphere and the upper sea layer are seen mainly during springtime.

The physiographic changes during the past 15 years can be seen, e.g. changes in albedo (Burgan Area, Kuwait, 1991, 1992, 1993, 1994), dust storm patterns, appearance of new borders (Kuwait) and changes of coastlines of Member States in the Region. The changes are due to natural environmental processes and human impact. During the 1991 War, a significant part of the Northwestern part of RSA desert surface was disturbed by large-scale war operations, pollution and subsequent clean-up operations. As a result, changes in vegetation cover and sand movement patterns were observed. In cloudless conditions, changes are seen in vegetation cover and density and coastal wetlands due to changes in the precipitation and cloud formation. The cloud net radiative effect, cooling or heating, depends on cloud type, which is controlled by: the surface and air temperature, wind speed and direction, atmospheric humidity, aerosol concentration, local sources of pollution, geographical patterns of the region, etc.

(FOLLOWING PAGES-TOP) **FIGURE II.3 : THE SPRING SET OF IMAGES FROM DIFFERENT NOAA WEATHER SATELLITES FOR APRIL - MAY (1985 - 1999)**

(FOLLOWING PAGES-BOTTOM) **FIGURE II.4 : THE AUTUMN SET OF IMAGES FROM THE SAME WEATHER SATELLITE SYSTEM FOR OCTOBER- NOVEMBER (1986 - 1998)**



# SPRING

NOAA AVHRR

SPRING  
1985

*April*

SPRING  
1986

*May*

AUTUMN  
1986

*July*

AUTUMN  
1987

*October*







SPRING  
1987

*April*

SPRING  
1988

*April*

AUTUMN  
1988

*December*

AUTUMN  
1989

*December*

**AUTUMN**  
NOAA AVHRR



# SPRING

NOAA AVHRR

*April*

SPRING  
1989

*May*

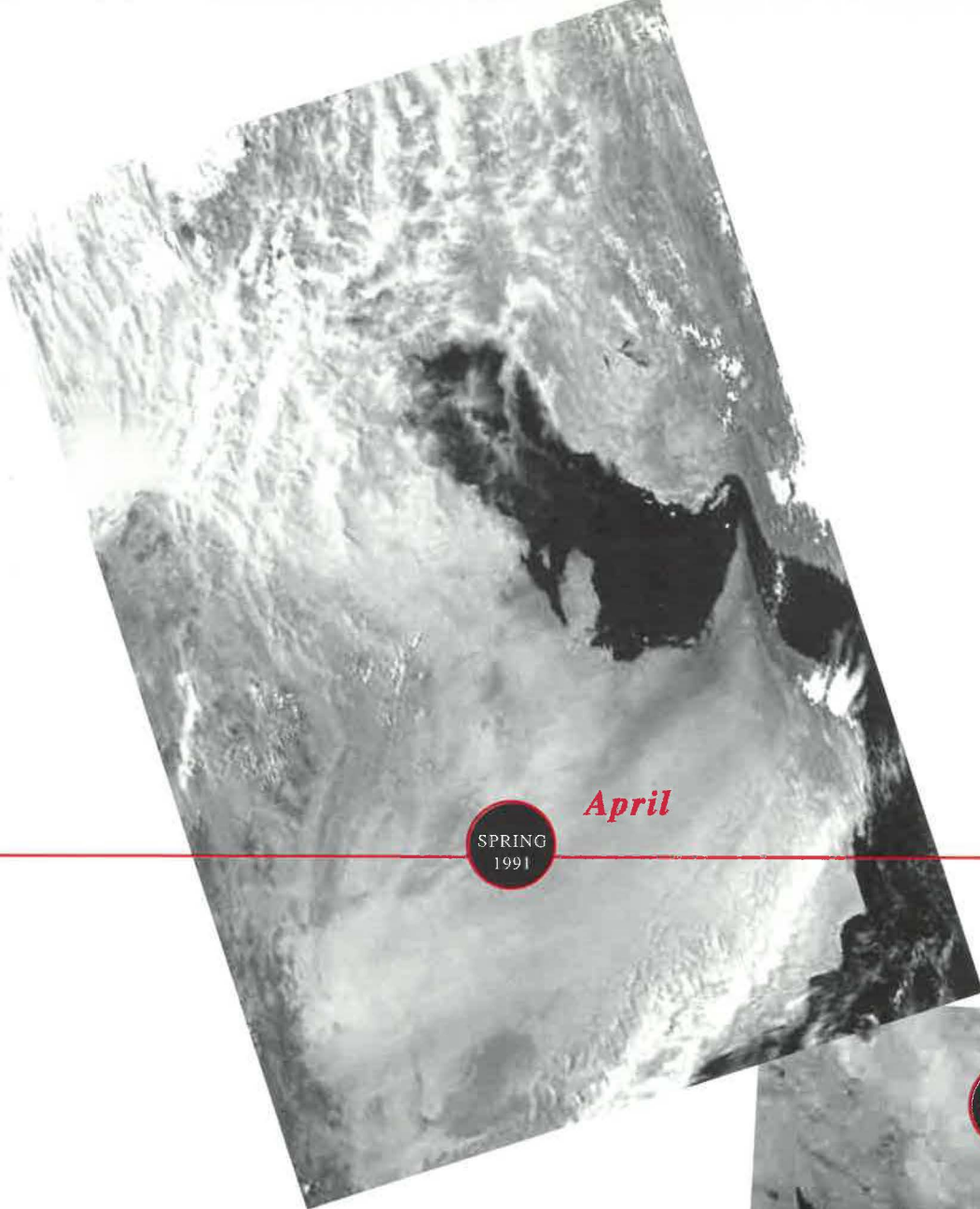
SPRING  
1990

*October*

AUTUMN  
1990

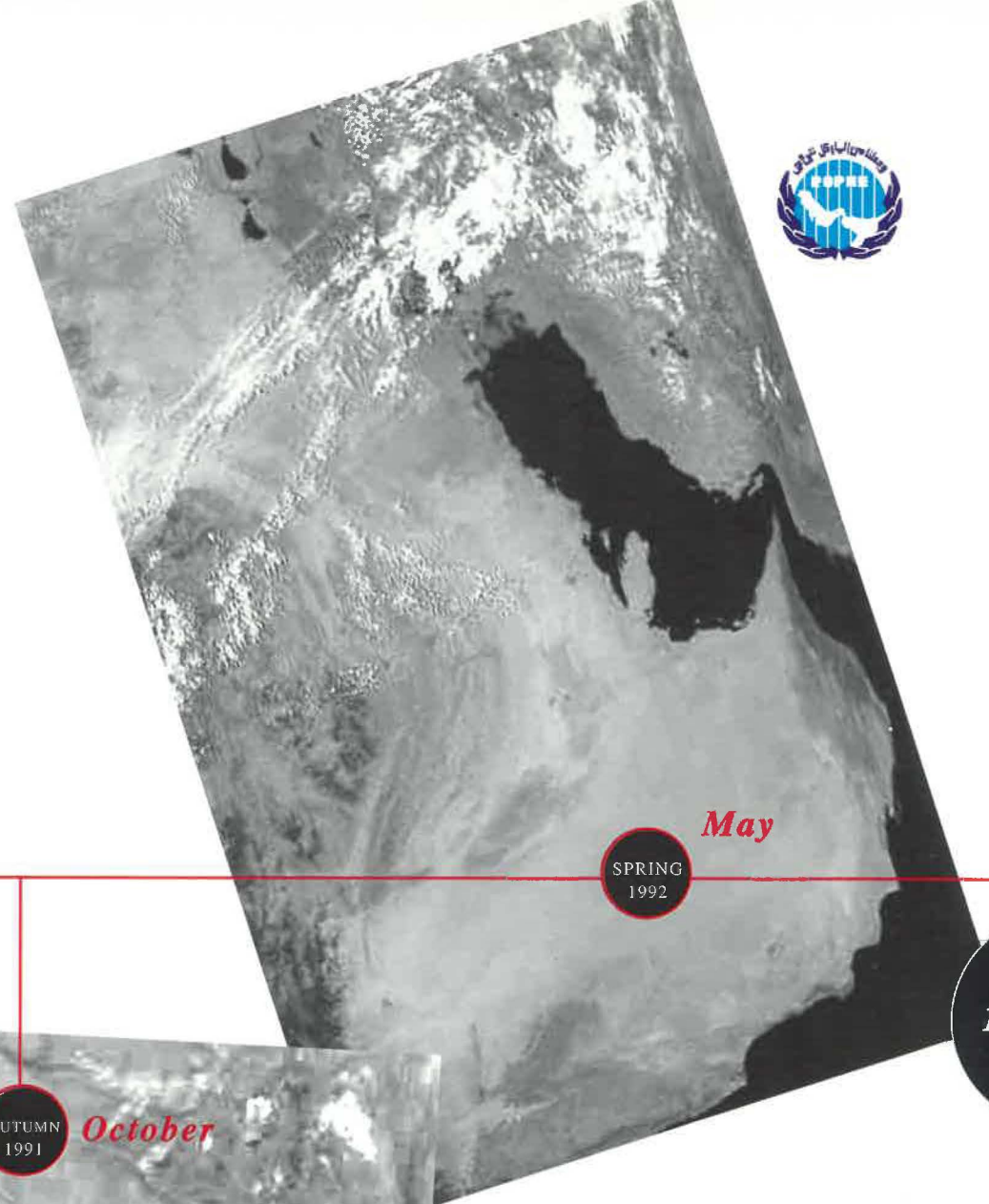






SPRING  
1991

*April*



SPRING  
1992

*May*



AUTUMN  
1991

*October*

**AUTUMN**  
NOAA AVHRR



# SPRING

NOAA AVHRR



20







*April*

SPRING  
1995

*April*

SPRING  
1996

*November*

AUTUMN  
1994

*October*

AUTUMN  
1995

**AUTUMN**  
NOAA AVHRR



# SPRING

NOAA AVHRR

*May*

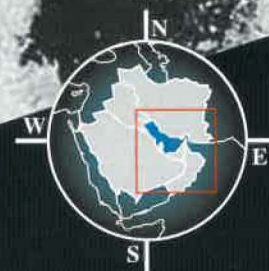
SPRING  
1997

*November*

AUTUMN  
1997

*October*

AUTUMN  
1996







*May*

SPRING  
1998

*April*

SPRING  
1999

*November*

AUTUMN  
1998

**AUTUMN**  
NOAA AVHRR







### III. LAND SURFACE FEATURES

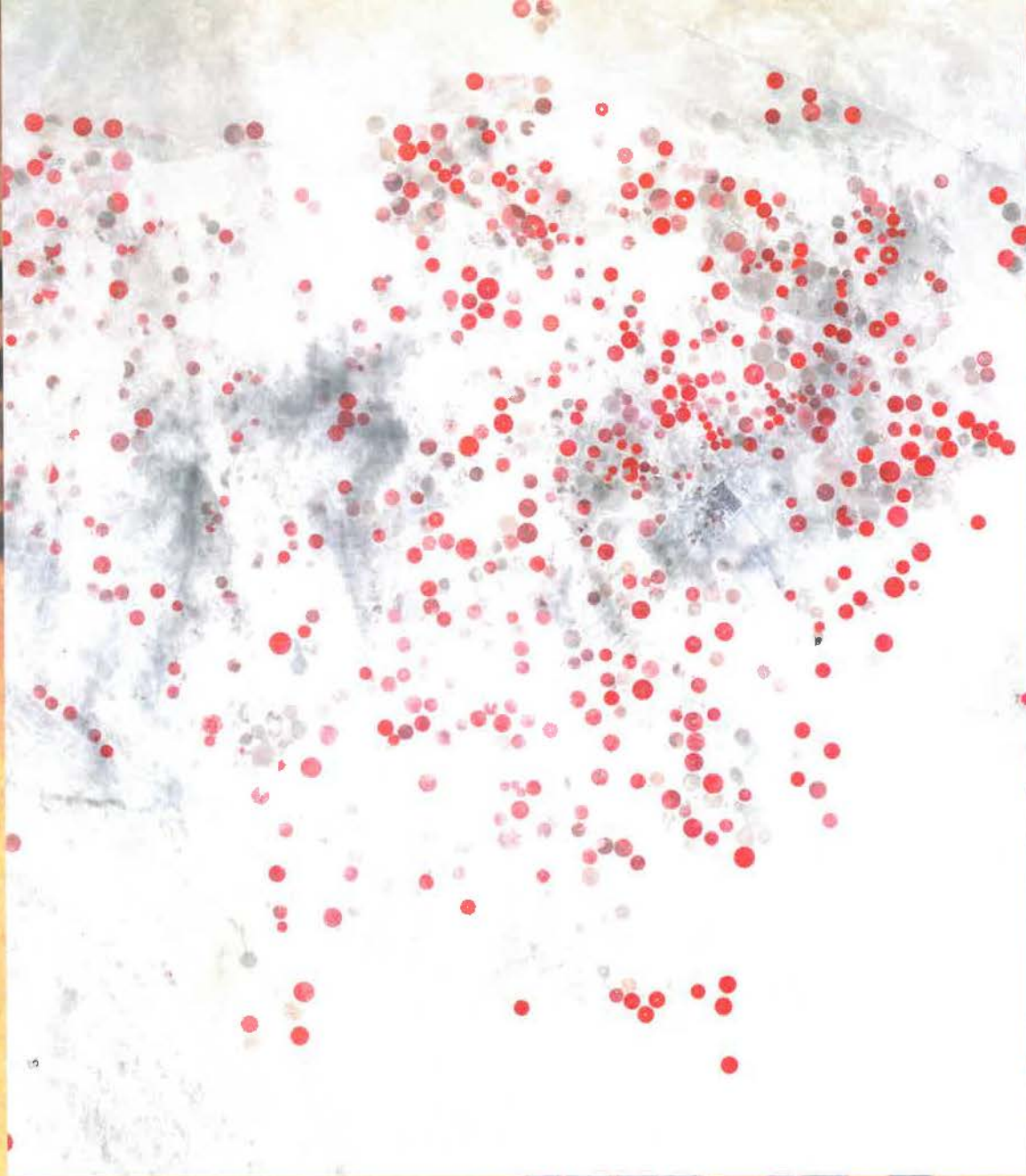
**F**or geological structures, including subsurface structures (those without relief formations on the surface), physical parameters such as: humidity, soil content, granularity, heat transfer, type and condition of vegetation, are responsible for the formation of optical and microwave properties of the surface that allow the formation of the RS image.

Low contrast (erosion) of the structural appearance on the surface acts as a low frequency filter on the structural level. It is difficult to see a clear picture of this using light aerial observations. From the orbital RS observation, the field of view of a picture decreases and generalization of all the structure appears. This principle is possible to apply to various processes on the earth's surface, including oceanography, coastal and terrestrial ecosystems. The ability to integrate the various classes of natural formation into newly defined classes represents one of the main achievements of structural analysis in RS.

For recognizing different levels of thermal emissivity, conductivity, capacity and inertia by surface materials, the method of Thermal Inertia is used. The Apparent Thermal Inertia is calculated from the day and night images in VNIR and thermal infrared (TIR) region. Some materials, such as rocks and concrete, with low thermal inertia have high daytime and low night time temperatures.

(LEFT) A VIEW OF THE VALLEYS OF THE RIVERS KARKHEH, DEZ AND KARUN, VEGETATION APPEARS IN RED, URBAN AREAS - IN BLuish - GREY. IT IS POSSIBLE TO SEE MARSHLAND AREAS. LANDSAT MSS, 1975. RGB COLOUR COMBINATION OF BANDS 4, 2, 1.









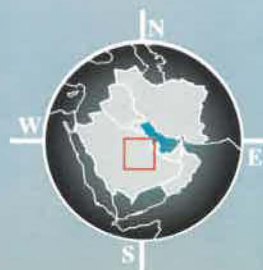
# Land Surface Features

III.1A

INTENSIVE IRRIGATED AGRICULTURE IN SAUDI ARABIA. STS 032-96-32, N20°, E45°, NATIONAL SCALE DATA.

RGB COLOUR COMPOSITION: TRUE COLOURS, SPACE SHUTTLE OBSERVATIONS, (APT J. ET ALL, 1996).

FIGURE ON FAR SIDE SHOWS INTENSIVE AGRICULTURE IN THE ARID LANDS OF SAUDI ARABIA. VEGETATION APPEARS REDDISH. PANCHROMATIC AND RGB COLOUR COMBINATION OF BANDS 4, 3, 2. LANDSAT 7, 2000.

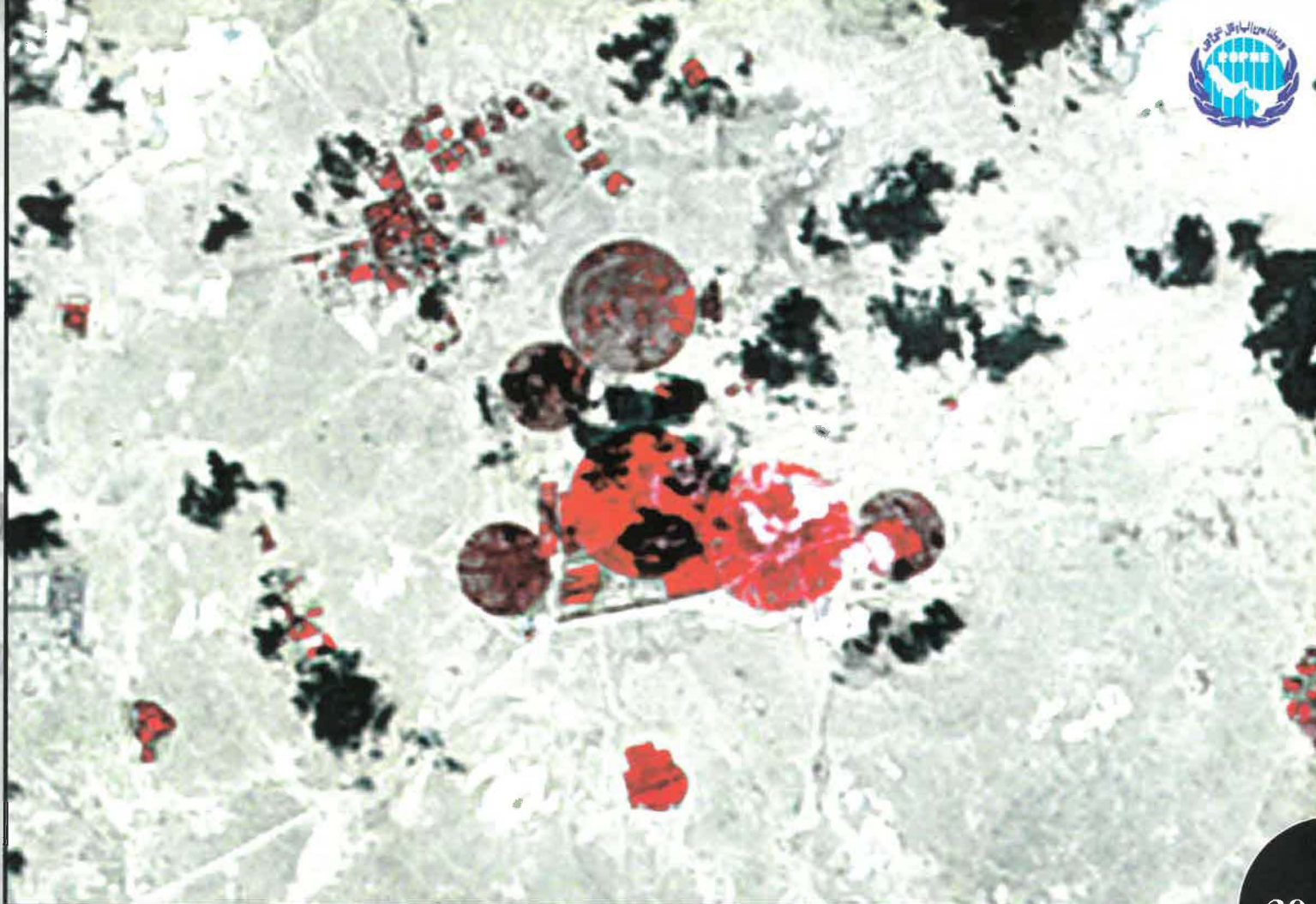


III.1A









(ABOVE RIGHT): INTENSIVE IRRIGATED AGRICULTURE IN QATAR. LANDSAT 5, THEMATIC MAPPER, FROM FEBRUARY 1995. THE FRAGMENT IS FROM THE FULL FRAME IMAGE. NATIONAL SCALE DATA. RGB COLOR COMPOSITION: BANDS 4, 3, AND 2. SPATIAL RESOLUTION: 30M / PXL. THE IMAGE IS PART OF THE NORTHEAST OF QATAR IN DETAIL. IRRIGATED FARMS, CIRCLES AND SQUARES APPEAR IN RED COLORS, WHICH SHOW RICH VEGETATION. DARK AREAS REPRESENT CLOUD SHADOW.



WASTELANDS APPEAR AS LIGHT GREY. IN COMPARISON WITH FIG III.1A, LANDSAT TM HAS A LOWER RESOLUTION, BUT A BETTER INTERPRETATION QUALITY, BECAUSE OF ITS DIGITAL AND MULTI-SPECTRAL BEHAVIOR OF DATA.



(LEFT): IRRIGATED AGRICULTURE IN KUWAIT - WAFRA. LANDSAT 7, ENHANCED THEMATIC MAPPER. THE FRAGMENT IS FROM THE FULL FRAME IMAGE, (NATIONAL SCALE DATA).

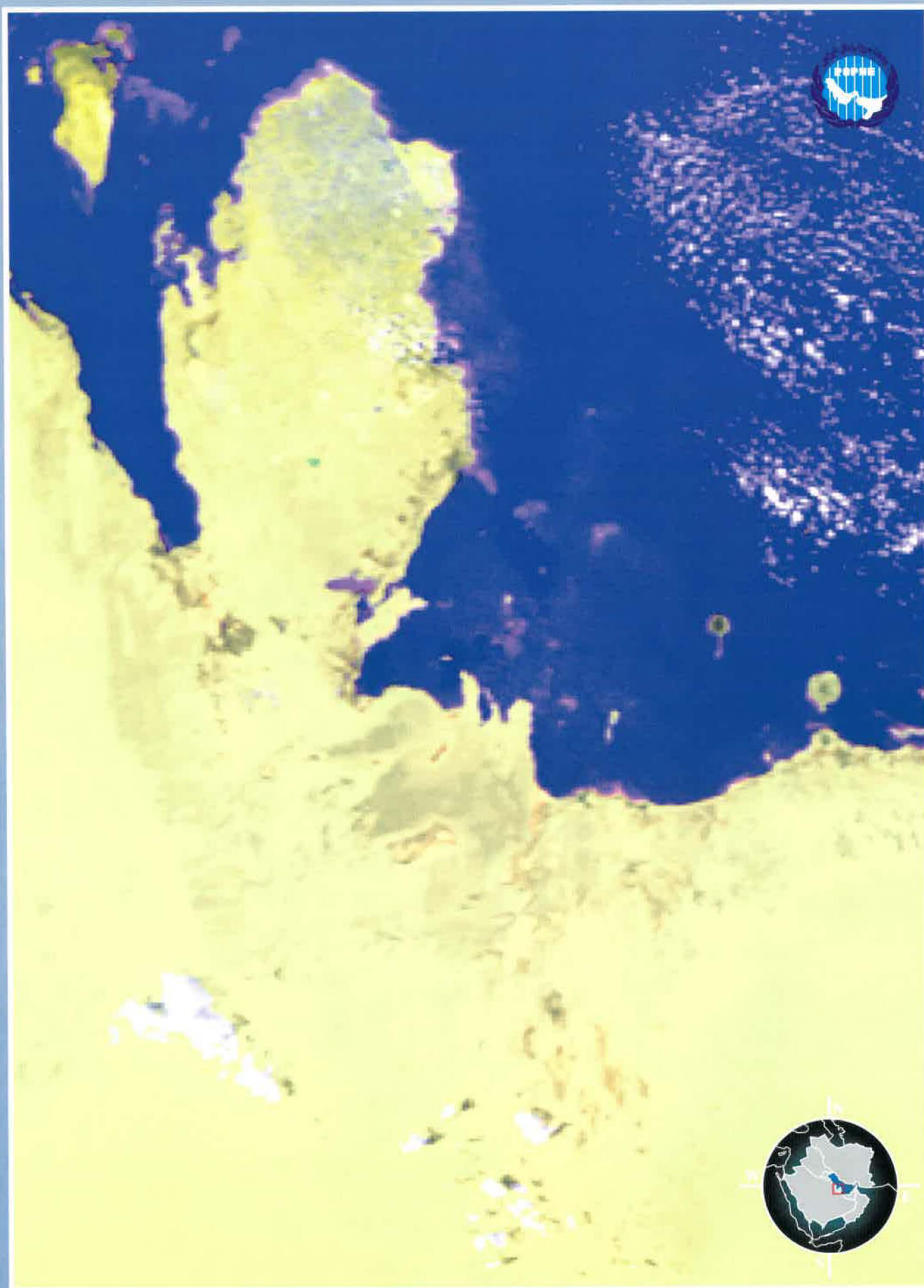
MERGING IMAGES HAVE PANCHROMATIC (15 M/PXL) AND RGB COLOUR COMPOSITION (BANDS 4, 3, AND 2, 30M/PXL). THE IMAGE IS PART OF THE SOUTH OF KUWAIT IN DETAIL. IRRIGATED FARMS, APPEARING IN RECTANGULAR PLOTS IN RED COLOURS, WHICH SHOW RICH VEGETATION. HIGH WAYS (IN DARK) AND LOCAL ROADS (IN LIGHT) APPEAR ON THE DESERT SURFACE. MARSHES APPEAR AS DARK PATCHES. WASTELANDS APPEAR AS LIGHT GREY IN KUWAIT TERRITORY AND DARK GRAY IN SAUDI ARABIA TERRITORY. LANDSAT 7 ETM HAS A BETTER RESOLUTION, AND A HIGH INTERPRETATION QUALITY.





III.2A

INTEGRAL MULTI-  
SPECTRAL VIEW OF  
SABKHA MATTI  
(UAE). NOAA /  
AVHRR RGB COLOUR COM-  
POSITION CH1, CH2, CH3  
WITH RESOLUTION 1 KM.  
GRADATION OF HUMIDITY IN  
THE SABKHA AREAS CAN BE  
SEEN, DEPENDING ON THE  
DISTANCE FROM THE COAST-  
LINE. VARIOUS DISSOLVED  
SALTS AFFECT THE COLOUR  
OF THE BACKGROUND SAND.





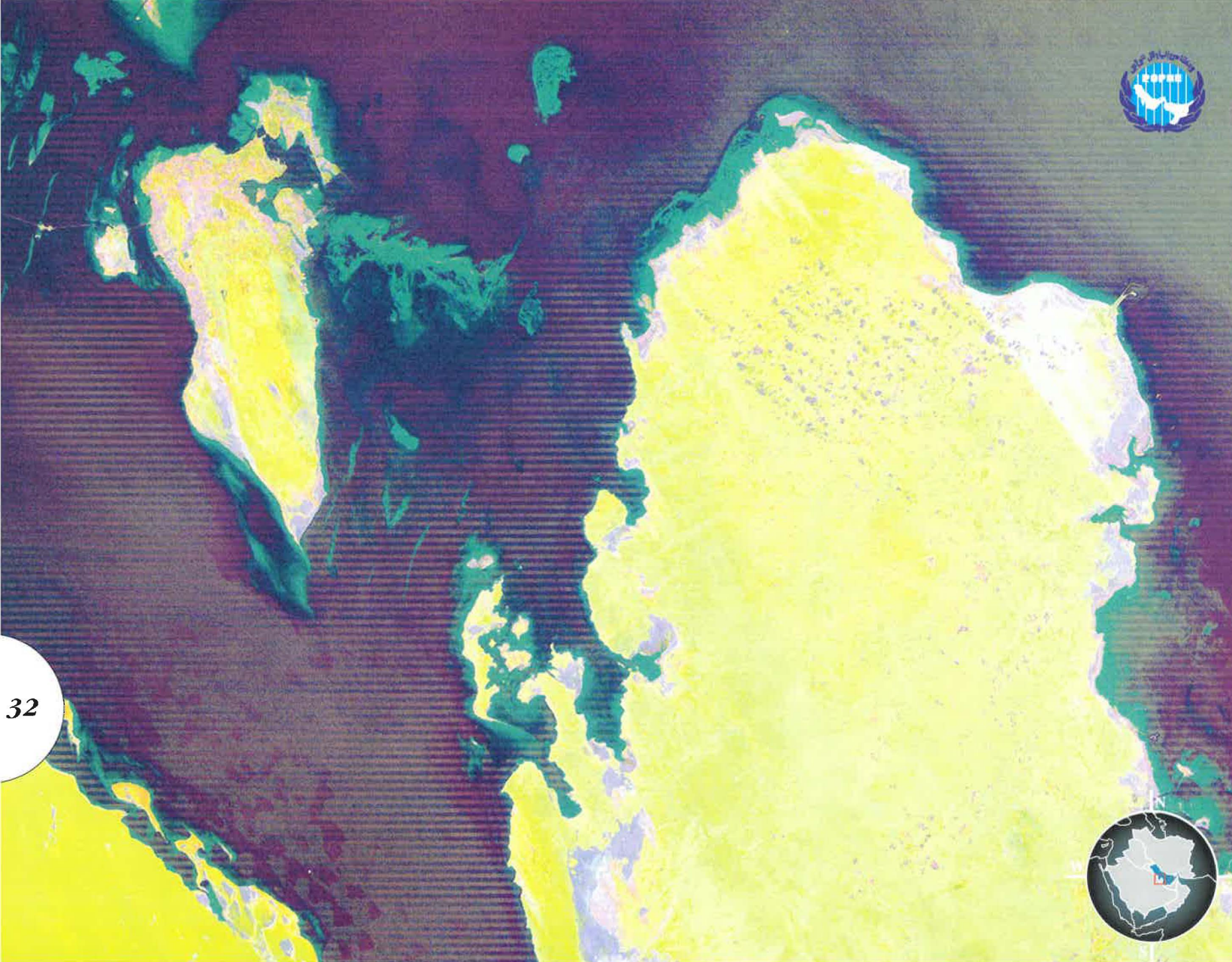
**T**he presence of water has a significant effect on RS images of deserts. Water can transfer arid lands into oasis gardens. Figs. III.1a and III.1b show the arrangement of circles of irrigated land in Saudi Arabia (Fig. III.1a, Space Shuttle cameras observation) and Qatar (Fig. III.1b, Landsat TM fragment). The diameter of such circles around artesian wells extends for several hundred meters, which is easy to trace from remote sensing platforms.

Figure III.1c (Previous Page-Left Side) shows the irrigated farms in Kuwait (Landsat 7 ETM fragment, 2000).

Another characteristic feature of deserts (arid lands) are their mineral deposits. The mineral characteristics, vegetation cover and soil texture influence remote sensing observations. For example:

- IN THE VISIBLE RANGE, THE YELLOW REGION IS RELATIVELY LESS DISTURBED BY ATMOSPHERIC EFFECTS.
- IN THE VISIBLE AND INFRARED RANGE (VIR) IN CLOUDLESS CONDITIONS, LANDSAT TM HAS FOUND WIDE APPLICATIONS FOR MAPPING MINERALIZED ZONES.
- USUALLY SATELLITE IMAGES, INCLUDING DESERT ENVIRONMENT, HAVE LARGE BRIGHTNESS CONTRAST, CAUSED BY BRIGHT SOILS AND DARK OASES OF VEGETATION.
- THE COLOUR / SPECTRAL FEATURES DEPEND ON STRUCTURAL ATTRIBUTES OF THE SAND, SUCH AS: HUMIDITY, GRANULARITY, ETC.
- IN GENERAL, THE DIFFUSING BEHAVIOR OF SAND REFLECTION ALLOWS OBSERVATIONS TO BE CARRIED OUT WITHOUT DEPENDING ON VIEW DIRECTION (I. E. TO USE SENSORS WITH WIDER FOV (LARGER FIELD OF VIEW).
- HUMIDITY OF THE SOIL FORMS VARIOUS COLOURS, WHICH ARE DARKER WITH INCREASED WATER CONTENT. IT IS POSSIBLE TO SEE IN FIGS III.2A AND B, GRADATIONS OF HUMIDITY IN THE SABKHA AREAS. THE GRADATIONS OF COLOUR DEPEND ON THE DISTANCE FROM COASTLINE. SABKHAS ARE COASTAL LOW LANDS WHERE THE DEPOSITS CONTAIN LARGE QUANTITIES OF EVAPORITES, WHICH AFFECT THE COLOUR OF THE BACKGROUND SAND. VARIOUS SALTS, DISSOLVED IN WATER, ARE ABLE TO AFFECT THE COLOUR OF THE SAND.
- USING LAND MEASUREMENTS, IT IS POSSIBLE TO DIFFERENTIATE ABOUT 200 COLOURS OF SAND. REMOTE SENSING CONFIRMS THESE FINDINGS IN VARIOUS ARID LANDS. MORE SATURATION OF YELLOW AND RED COLOURS IN THE VISIBLE RANGE OF SPECTRA IS CAUSED BY THE RELATIVELY HIGHER TRANSPARENCY OF THE ATMOSPHERE IN THIS SPECTRAL INTERVAL.



**III.2b**

COASTAL FEATURES ON THE WEST COAST OF CENTRAL PART OF RSA. BAHRAIN, NORTH QATAR AND SAUDI ARABIA COAST. THE SABKHA AREAS APPEAR IN GRAY-BLUE. CORAL REEFS AND SAND BANKS AND INTER-TIDAL ZONE APPEAR IN GREEN. DARK SPOTS IN THE SEAWATER REPRESENT THE BOTTOM SEA GRASS PATCHES. URBAN FABRICS (DOHA AND MANAMA) APPEAR AS LIGHT REDDISH-BROWN.

LANDSAT 5 TM, FROM FEBRUARY 1995, APPLYING IMAGE PROCESSING OF CH1, CH2, CH3, CH4, CH5, CH7, INCLUDING DIGITAL FILTERING AND EQUALIZATION. RESOLUTION IS 30M PER PIXEL. GRADATIONS OF HUMIDITY IN SABKHA AREAS, DEPENDING ON THE DISTANCE FROM THE COASTLINE, AFFECT THE COLOURS OF BACKGROUND.



**A**s for the interpretation of images, the following patterns may be identified in relation to mineral characteristics, vegetation cover and soil texture:

- THE ARABIAN PENINSULA APPEARS IN RED, MOSTLY DESERT WITH THE SIGNIFICANT APPEARANCE OF SAND DUNES. SOMETIMES IT IS POSSIBLE TO TRACE DARK COLOURED SPOTS. THE ABUNDANCE OF TEXTURES IS SHOWN IN FIG III.3. IT ALSO SHOWS THE HETEROGENEITY IN COLOUR CONTRASTS OF THE DESERT SURFACE AND ITS COMPOSITION IN DIFFERENT SPECTRAL BANDS.
- THE NON-LAMBERTIAN REFLECTANCE EVIDENT IN THE AVHRR TIME SERIES REPRESENTS A LARGER SCALE OF EFFECTS, SUCH AS DUNE GEOMETRY IN ARID ENVIRONMENTS.
- POLARIMETRIC RADAR EXPERIMENTS SHOW FAIR CLASSIFICATION CAPABILITIES WITH RESPECT TO THE CONDITIONS OF BARREN SOILS.
- CLAY IS BOTH A REFLECTOR AND ABSORBER OF RADAR WAVES.
- DRY SAND AND GRAVEL ARE EXCELLENT RADAR TRANSMITTERS.
- IN AN UNDISTURBED OR HOMOGENEOUS ARID ENVIRONMENT, A ROUGH SURFACE APPEARS DARKER THAN A SMOOTH SURFACE, EVEN IF BOTH SURFACES HAVE THE SAME COLOUR. VEHICLE TRACKS CHANGE THE TEXTURE OF THE GROUND BY LEAVING CLEARLY VISIBLE TRACK MARKS.
- AFTER RAINFALL, DIFFERENTIAL DRYING PATTERNS CAN ALSO BE IDENTIFIED.
- THE CORRECTIONS FOR THE SOIL EFFECT USING VARIOUS VEGETATION INDICES SHOW NO OBVIOUS RELATIONSHIP BETWEEN THE INDICES AND PERCENTAGE VEGETATION COVER IN ARID LANDS.
- INCREASING VEGETATION COVER IN ARID ENVIRONMENTS IS OFTEN ASSOCIATED WITH A DARKENING EFFECT DUE TO LEAF ABSORBENCY AND THE EFFECTS OF SHADOWING.



**III.3** DESERT AREAS BETWEEN OMAN, SAUDI ARABIA AND UAE.

DIFFERENT TEXTURES OF ARID LANDS SHOW THE HETEROGENEITY OF THE DESERT SURFACE.

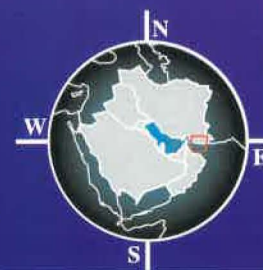
NOAA/AVHRR, RGB colour composition, ch1, ch2, ch3 with resolution 1km.





III.4

A DUST STORM IN THE SOUTHEASTERN PART OF THE RSA, I.R. IRAN COAST AND GULF OF OMAN, OBSCURING MOST OF THE IRANIAN COAST AND EXTENDING MANY KILOMETERS INTO THE SEA. RGB COLOUR COMPOSITION IMAGE (TRUE COLOURS), (NASA, GSFC ARCHIVE).





**S**and storms and clouds are widely distributed phenomena in arid lands. Just 6-10 m/s of wind speed is enough to generate sandstorms over arid lands in the Region. Dust storms and dust clouds transfer large amounts of particulate matter for a distance of hundreds or thousands of kilometers. This is similar to the sediment transport mechanism of rivers, except that it is on a much bigger scale. In comparison with rivers (1-2 km wide), the width of a dust storm/cloud is hundreds of kilometers. The speed of a dust storm cloud is about 60km/h, while the speed of river flow is only a few km/h. Most of these particulates are from exposed desert surfaces or dry irrigated lands located in the path of the blowing winds.

The RSA is a typical place for major dust storms. Despite a long history of research on dust storms, the use of space remote sensing in this field has been limited. Remote Sensing is a unique tool for the estimation of sources and generated forces, sizes, dynamics, and direction of transfer. It is an excellent instrument for understanding the environment on a regional scale. In Figure III.4, it is possible to see dust storms in the southern part of RSA (I.R. Iran). The dust cloud decreases the contrast of the coastline. The density of the cloud quickly goes down over the sea surface. The heavier particles settle down over the sea. Usually the source of dust is from inland areas, including the coastal areas. Most of the time, dust clouds (suspended particulates) exist for a few days, and later spread (dissipate) over the sea surface. The main fall out of the dust cloud occurs over the sea, becoming a major source of bottom sediments. Remote sensing observations of this phenomenon show that it is global. Thus, dust moves over practically the entire planet. It should be noted that anthropogenic influences could change the factors generating this phenomenon.

The composition of aerosol particles in the coastal zones varies from aluminum silicates (Al, Ca, Si and O<sub>2</sub>), originating from the coastal shelf (soil, rocks), to solid NaCl particles formed by water evaporation over the coastal sea. Polluted regions can contain sulfates or nitrogen oxides. Only satellite remote sensing gives the global distribution of aerosols and their optical properties. Aerosol measurements rely chiefly on the scattering of sunlight, utilizing nadir-viewing techniques for troposphere aerosols, or limb scanning instruments for stratospheric aerosols.

A dust storm in the southeastern part of the RSA, I.R. Iran coast and Gulf of Oman is shown on Fig III.4. It is an RGB Colour composition image (True colours) from October 1984, Space Shuttle Observation (NASA, GSFC Archive).





III.5b





(LEFT) FIGURE III.5A  
INTEGRAL MULTISPECTRAL  
VIEW OF THE MESOPOTAMIAN  
MARSHES, SHOWING THE TIGRIS  
AND EUPHRATES FORMING  
SHAT AL ARAB, WITH MARCHES  
MOSTLY DRY ON BOTH SIDES OF  
THE RIVERS, 1997.

RGB COLOUR COMPOSITION  
IMAGE OF CH1, CH2, CH4.  
NOAA / AVHRR FRAGMENT  
WITH RESOLUTION 1 KM/PIXEL.

Satellite observations allow us to study in detail hydrology and river geometry, erosion of riverbanks, changes in irrigation channels and river valleys, as well as sedimentation and morphology of river beds, evolution of river deltas and river outfalls into the sea. Constructions of dams on the Tigris and Euphrates have induced major changes in the hydrographic regime of these main sources of fresh water in the region, which could severely disturb the North RSA ecosystems.

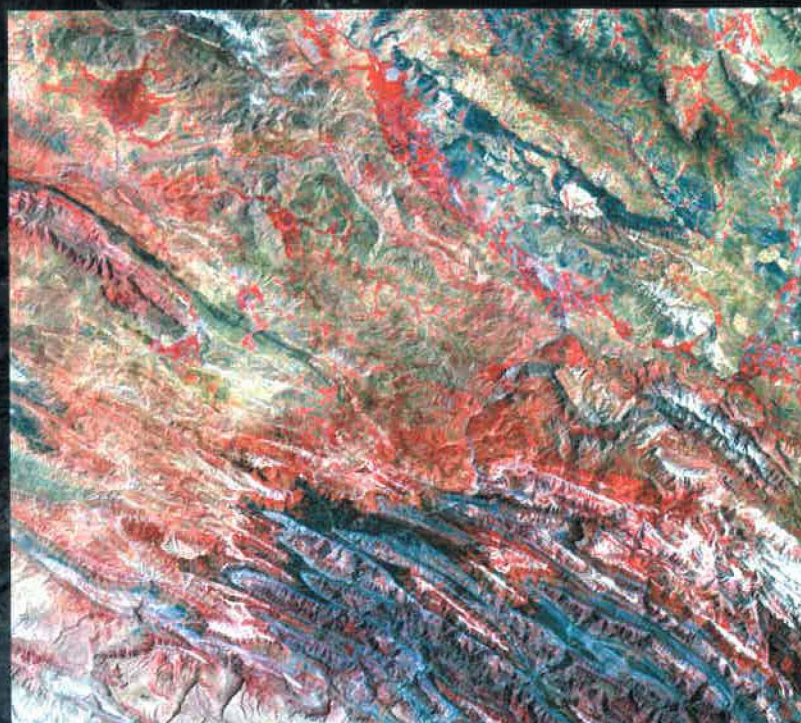
(OPPOSITE PAGE) INTEGRAL MULTISPECTRAL VIEW OF THE  
MESOPOTAMIAN MARSHES, SHOWING THE TIGRIS AND EUPHRATES  
RIVERS FORMING SHAT AL ARAB, WITH MARSHES MOSTLY DRY ON BOTH  
SIDES OF THE RIVERS, 2000. THE MELIORATION WORKS INCLUDE  
DRAINAGE OF SOUTH MESOPOTAMIAN MARSHES. DRY AREAS ARE A LIGHT RED-  
DISH. VEGETATION IS SHOWN IN GREEN.

RGB COLOUR COMPOSITION IMAGE OF CH7, CH4, CH2. LANDSAT ETM FRAG-  
MENT WITH RESOLUTION 30 M/PIXEL, 2000.



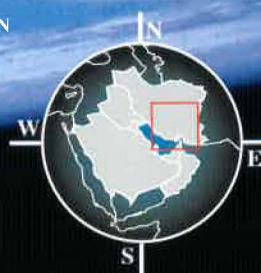


# Forests & Mountains



WEST IRAN, FRAGMENT FROM ZAGROS MOUNTAINS, VEGETATION APPEARS REDDISH. LANDSAT MSS, 1975. RGB COLOUR COMBINATION OF BANDS 4, 2, 1.

III.6A FOREST AREAS, ZAGROS MOUNTAIN CHAIN - EASTERN PART OF THE RSA, I.R. IRAN COAST. RGB COLOUR COMPOSITION IMAGE IN TRUE COLOURS (STS 027-152, N29°, E53°). NASA, SPACE SHUTTLE OBSERVATIONS, (APT J. ET AL., 1996). NATIONAL SCALE DATA.

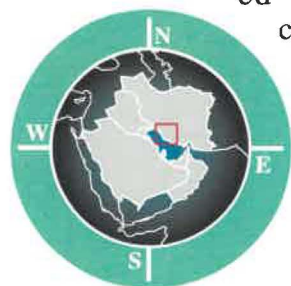




**F**orests typically show low saturation of colours, namely dark grey and blue tones and low reflectance. It is possible to see the typical forest areas on the Iranian Zagros Mountains.

The spatial resolution of the instrument affects the accuracy of the mapping. Using 10m SPOT panchromatic band in the classification of 30m TM could improve the accuracy to about 70%. TM data are more effective in separation shrubs from meadows than SPOT, but neither are capable in separating meadows types. TM allows the accurate separation of evergreen and mixed forests and allows mapping of forest types with an accuracy of about 90%, while the accuracy of forest classification, using SPOT with 20m resolution could drop to 70%. Various transformations such as perpendicular, transformed and normalized difference vegetation index (NDVI) have been used for vegetation study. NDVI can also be used for the estimation of various types of salt affected soils. Rationing has been widely used in

change detection studies. The ratio of the first two MSS bands (green and red) is found to be associated with the changes in the spatial distribution of the salt-affected soils. Various studies have shown a strong relationship between NDVI and rainfall in semi-arid environments.

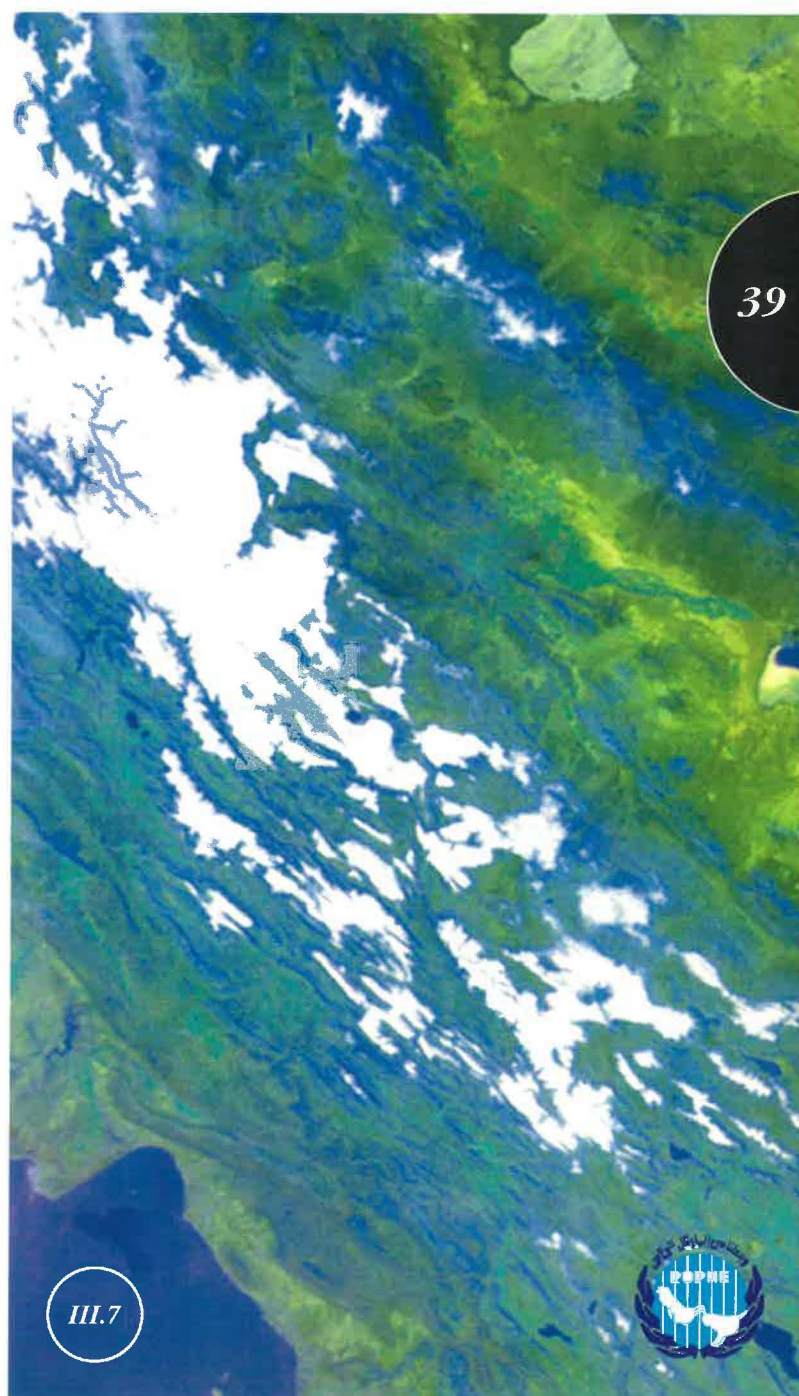


Spectral contrasts of forest formations are connected with the geological features and topography of the area. The observation of forests requires spectral reflectance method, which depends on the sun's location.

**(RIGHT TOP) INTEGRAL MULTISPECTRAL VIEW OF THE ZAGROS MOUNTAIN CHAIN - EASTERN PART OF THE RSA, I.R. IRAN COAST. NOAA / AVHRR. RGB COLOUR COMPOSITION IMAGE, CH1, CH2, CH3 OF FOREST AREAS WITH RESOLUTION 1 KM/PIXEL.**

**S**now cover is one of the major sources of fresh water in this region. It is possible to see the snow cover of the Zagros Mountain chain. It is also possible to see the boundaries of the snow cover, and to reveal the influence of the wind in forming the distribution of snow. Analyses of the snow albedo and coverage are useful indicators of regional climate changes and pollution deposition.

**(RIGHT BOTTOM) SNOW COVER OVER THE ZAGROS MOUNTAIN CHAIN NOAA / AVHRR FRAGMENT OF MULTI-SPECTRAL VIEW OF THE ZAGROS MOUNTAIN CHAIN - NORTHEASTERN PART OF THE RSA (I.R. IRAN COAST) WITH RESOLUTION 1 KM. RGB COLOUR COMPOSITION IMAGE (CH1, CH2, CH3). SNOW COVER APPEARS IN WHITE COLOURS.**



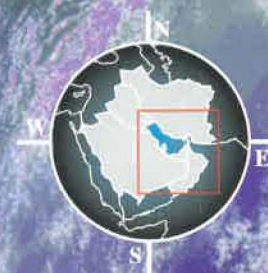




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IV.1A

ROPME REGION FROM SPACE. CLOUDY CONDITIONS (EAST I.R. IRAN, OMAN AND THE SOUTH OF SAUDI ARABIA) NOAA 14 AVHRR IMAGE FROM MARCH 1997. COLOR COMPOSITION OF VISIBLE AND IR BANDS, CH1, CH2, CH3 WITH SPATIAL RESOLUTION 1 KM/PIXEL.





## IV. DISTRIBUTION OF VEGETATION

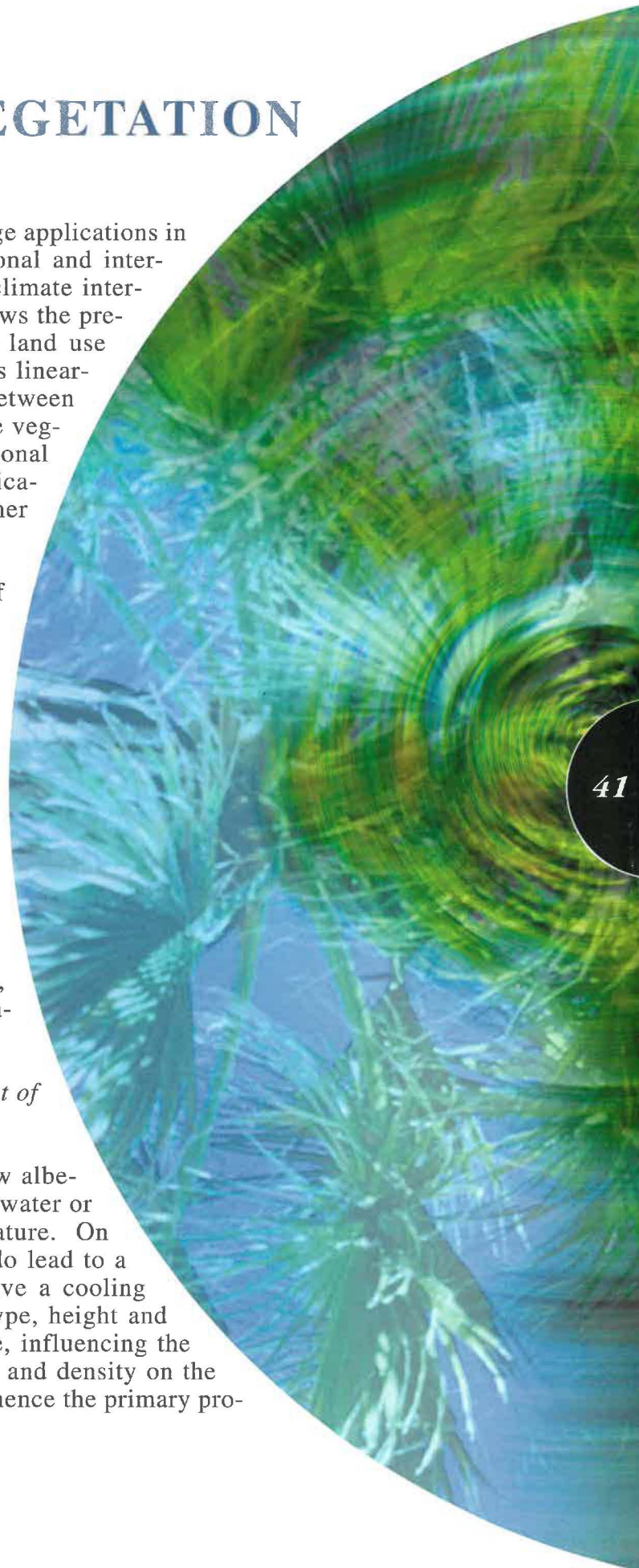
**T**he Normalized Difference Vegetation Index (NDVI) has found large applications in the remote sensing of vegetation and crop productivity, for seasonal and inter-annual analyses of land cover, and for the analysis of ecosystem/climate interactions. This is one of the major ecosystem characteristics and allows the prediction of long-term environmental consequences of climate and land use changes on ecosystem function and sustainability. NDVI generally responds linearly to leaf area. Many studies have supported the near-linear correlation between NDVI and the fraction of photosynthetically active radiation absorbed by the vegetation patterns. However, in the case of arid lands, NDVI needs additional assessment studies. RSA is a typical region for future assessment and application of the above approach. However, in general, soil is considerably warmer than foliage and the difference of temperatures could be up to 25 degrees C.

Vegetation controls evapotranspiration and photosynthesis as a function of the green leaf area index and the temperature. The aerodynamic temperature of vegetation depends on the physical, chemical and biological processes in vegetation, the growth cycle and productivity of the plants, crop yield, evapotranspiration from canopy and evaporation from soil. The canopy and soil temperatures are good indicators of salinity, water supply and water stress and are roughly equal soon after irrigation or rain. Irrigated fields of wheat show very small variations in diurnal temperatures. In dry land, when the canopy evaporation is generally low, the foliage temperature is higher if the soil surface is dry, and decreases soon after any irrigation or rain, modifying the crop microclimate. Many arid areas of the world are affected by soil salinity. Early detection of saline areas, and of the degree of salinity, may permit preventive measures before significant crop damage.

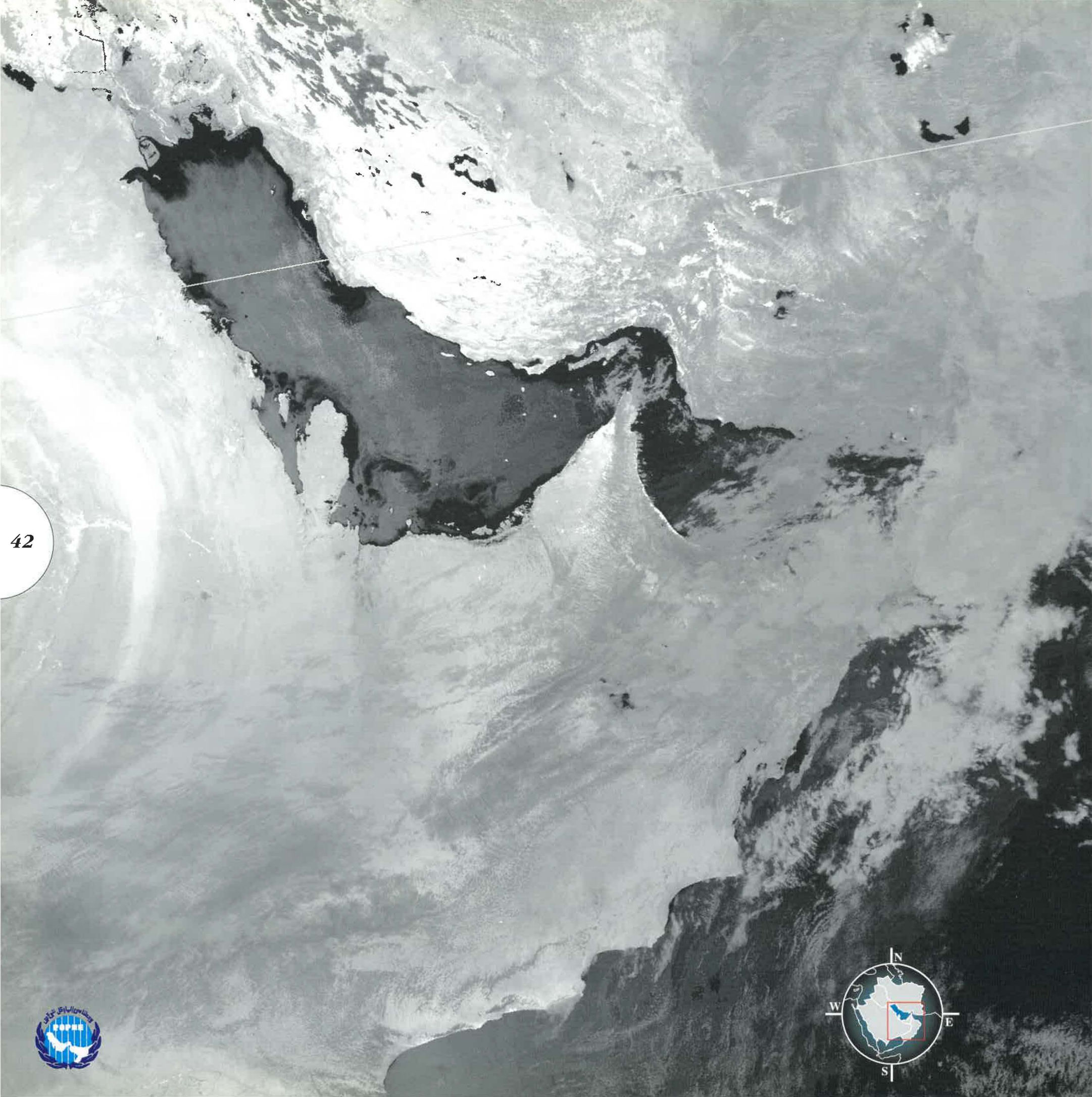
The temperatures of canopy, soil, evaporation and the evaporative fraction, measured by the thermal infrared (TIR) spectral satellite systems are indicators of the soil water supply.

*FIGURE IV.1A shows a large cloud system in the east covering east Iran, most of Oman and the outer part of the RSA (Gulf of Oman).*

High clouds, which have low liquid water or ice content and a relatively low albedo are stronger absorbers and emitters of infrared radiation due to the liquid water or ice content. They have a heating effect leading to a higher surface temperature. On the other hand, the lower clouds with higher liquid water content and albedo lead to a higher reflected solar radiation and lower surface temperature, so they have a cooling effect. The cloud heating or cooling effect depends mostly on the cloud type, height and microstructure. Thus, the cloud feedback can be either positive or negative, influencing the marine and land surface temperature. The clouds influence vegetation type and density on the land and the Photosynthetically Available Radiation (PAR) on the sea surface hence the primary production during the day.









# NDVI

IV.1B

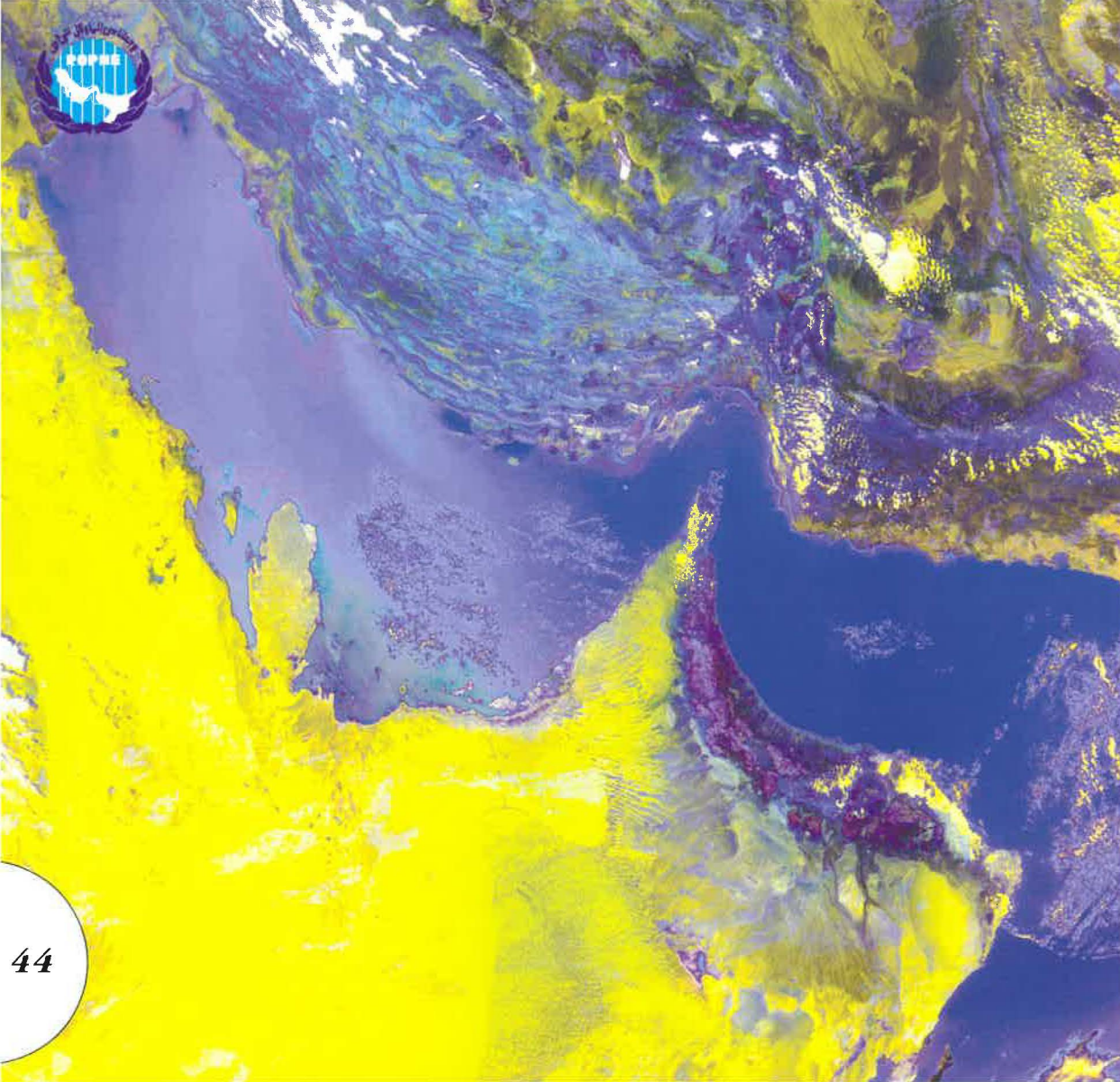
(LEFT): NORMALIZED DIFFERENCE VEGETATION INDEX (SINGLE SCENE NDVI) OF AN IMAGE FRAGMENT FROM FIGURE IV.1A (ROPME REGION), PROCESSED FROM NOAA 14 / AVHRR, MARCH 1997.

SCALAR HIGH CONTRAST IMAGE WITH SPATIAL RESOLUTION: 1KM/PIXEL IN THE SAME SCALE AND PROJECTION AS FIGS IV.1A.

WHITE AND LIGHTER SHADES OF GREY REPRESENT A HIGHER DENSITY OF VEGETATION, DARKER AREAS INDICATE LOWER DENSITY VEGETATION, CORRESPONDING TO ALMOST BARE SOIL. IRRIGATION FARMING APPEARS AS WHITE SPOTS AND PATCHES. SABKHA AREAS ARE A DARKER GREY. THE SEAWATER IS SHOWN AS A VERY DARK GREY/BLACK. THERE IS SOME CLOUD COVER IN THE SOUTH-EAST OF THE IMAGE, COVERING EASTERN IRAN AND OMAN AND SNOW COVER IS SHOWN IN THE NORTH-WEST BY A DARKER GREY.

The NDVI calculated by AVHRR is a good indicator of the land surface processes, vegetation type and density, primary productivity, evapotranspiration and atmospheric CO<sub>2</sub> dynamic.





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IV.2

ROPME REGION FROM SPACE (MASIRA TO SHATT AL-ARAB). SIGNIFICANTLY CLEARER ATMOSPHERE CONDITIONS.

NOAA 14 AVHRR IMAGE FROM MARCH 1997. COLOUR COMPOSITION OF VISIBLE AND IR BANDS, CH1, CH2, CH3 WITH SPATIAL RESOLUTION 1 KM/PIXEL. THE IMAGE IS OBTAINED IN SIGNIFICANTLY CLEAR ATMOSPHERIC CONDITIONS AND IN THE SAME SCALE AND PROJECTION AS FIGURE IV.1A.



THE MAIN FEATURES OF FIGURE IV.2 ARE AS FOLLOWS:

### - *Atmosphere*

There are significantly clear atmospheric conditions in the region.

Small cloud development is observed on the East, South and West, shown on the images as white and yellow contours.

### - *Seawater*

Seawater is dark blue to light greenish-blue in presentation.

The large dark blue area corresponds to the deep waters of Gulf of Oman.

Different colours show the sea-atmosphere interactions (North RSA), river plumes (Shatt Al-Arab, the Mond, etc.) and shallow waters (North RSA, Central part: Bahrain, Qatar, UAE).

### - *Coastal areas & Land Cover*

The white high contrast (sharp) contours on the peaks of the Zagros Mountains denote the snow cover in the North.

Flat desert sands are presented in a greenish-yellow colour on the west coast of the RSA.

The South Mesopotamia marshes are shown on the upper north-west corner of the image in dark green-blue.

Oman's Al-Hajar Al-Gharbi, Akhdar Mountains and Beshagrad Mountain chains in I.R. Iran are shown in a brown/dark purple colour on the East part of the image.

The large sabkha areas and salt desert are shown in darker greenish patches on the central west coastline of Saudi Arabia, Qatar, UAE, Oman, I.R. Iran and Iraq.

Disturbance of land surface texture depicts the borders of Kuwait on the left part of the image.

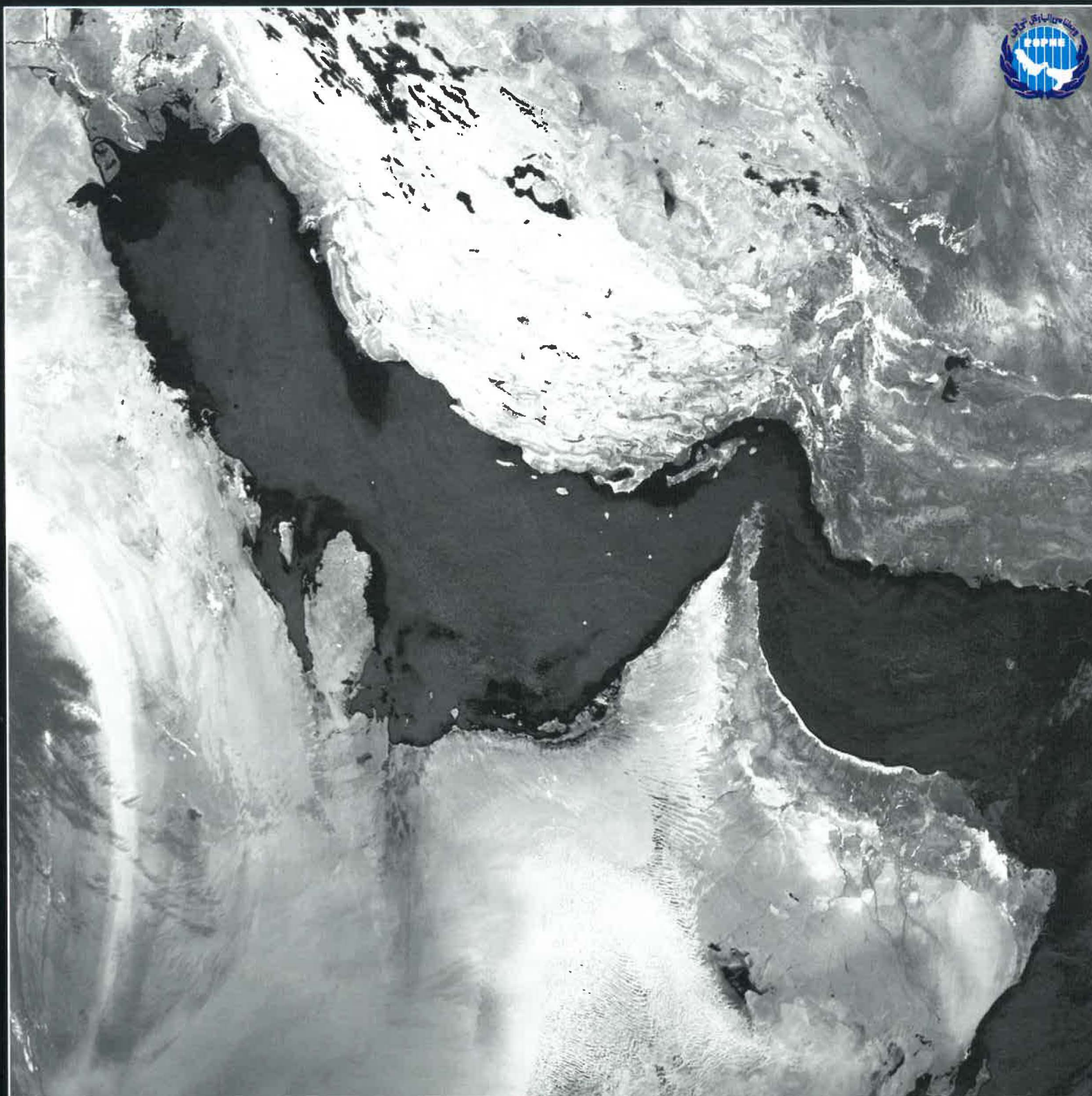


MAGNIFICATION OF FIGURE IV.2 SHOWING  
GREATER DETAILS OF THE CENTRAL PART OF  
ROPME SEA AREA.

IV.3

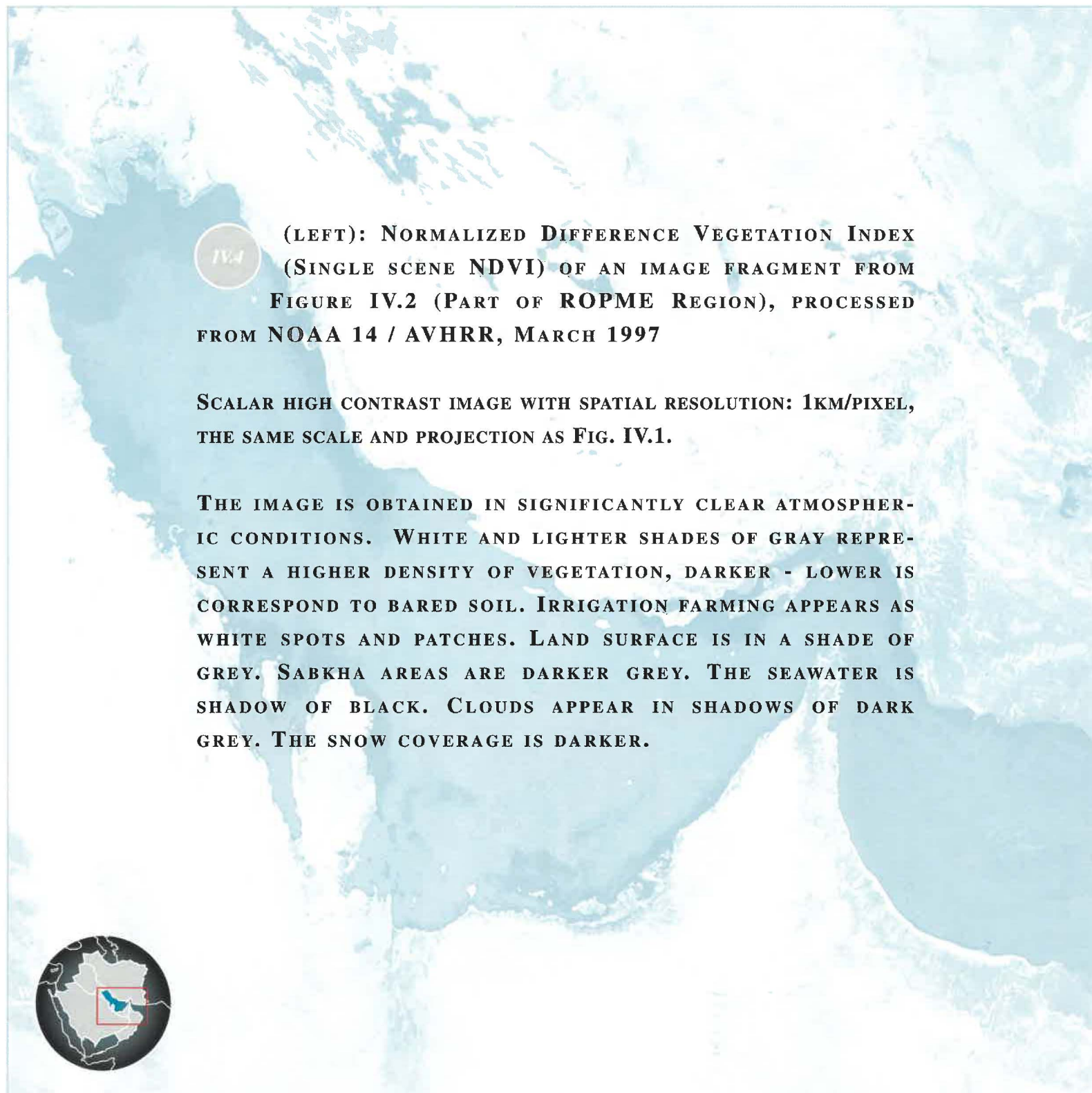








# NDVI









# NDVI



(LEFT): MAGNIFICATION OF NDVI SINGLE SCENE IMAGE OF PART OF THE ROPME REGION, PROCESSED FROM NOAA / AVHRR, MARCH 1997.

THE WHITE AND LIGHTER (BRIGHTER) SHADES OF GREY REPRESENT A HIGHER DENSITY OF VEGETATION, DARKER PARTS CORRESPOND TO BARREN SOIL. THE IRRIGATED FARMING AGRICULTURE AREAS, OASES, ETC. ON THE WEST COAST OF ROPME SEA AREA APPEAR AS WHITE SPOTS AND PATCHES (LOCATED IN KUWAIT, SAUDI ARABIA, QATAR, UAE, THE SEA COAST OF NORTHWEST BAHRAIN AND OMAN). THE IRANIAN COAST IS COVERED WITH VEGETATION, PASTURES AND SCATTERED FARMING WOODLANDS. THE VEGETATED AREAS NEAR THE RIVERS, CHANNELS (NORTH RSA, SHATT AL-ARAB) AND LAKES (I.R. IRAN) ARE VERY BRIGHT.

LAND SURFACE IS A SHADE OF GREY. IT INCLUDES ROUGH GRAZING / NOMADIC HERDING, BARE SOILS, URBAN AREAS, ETC. ROUGH GRAZING / NOMADIC HERDING AREAS IN SOME PLACES ARE OVERGRAZED AND APPEAR AS MORE DARKER GREY AREAS. EXAMPLES OF THESE AREAS ARE FOUND IN KUWAIT, SAUDI ARABIA, UAE AND OMAN. WETLANDS AND MARSHES OF SOUTH OF IRAQ, THE WEST COAST OF RSA AND QATAR, EAST OF IRAN AND OMAN APPEAR IN MORE DARKER TONES (SCARCE VEGETATION) AND IS IN CONTRAST WITH IRRIGATED FARMING SPOTS OF CENTRAL AND NORTH EAST QATAR AND NEAR THE CHANNELS OF SHATT AL-ARAB.

THE SABKHA AREAS ARE PRESENTED IN DARK GREY (SABKHA MATTI - UAE).

SEAWATER IS DARK AND IS PRESENTED IN VARIOUS SHADES OF GREY. THE SHALLOW WATERS WITH HIGH TURBIDITY ARE SHOWN IN BLACK (SHATT AL-ARAB, BAHRAIN, QATAR, QESHM ISLAND / IRAN). LAKES ALSO APPEAR AS BLACK SPOTS.

CLOUDS APPEAR IN SHADOWS OF DARK GREY, IN THE EAST (IRAN), SOUTH EAST (OMAN COAST AND GULF OF OMAN), AND SOUTH WEST (SAUDI ARABIA) OF THE IMAGE. SNOW COVERAGE IS IN BLACK (I.R. IRAN - THE ZAGROS MOUNTAIN) IN THE UPPER PART OF THE IMAGE.



# KUWAIT

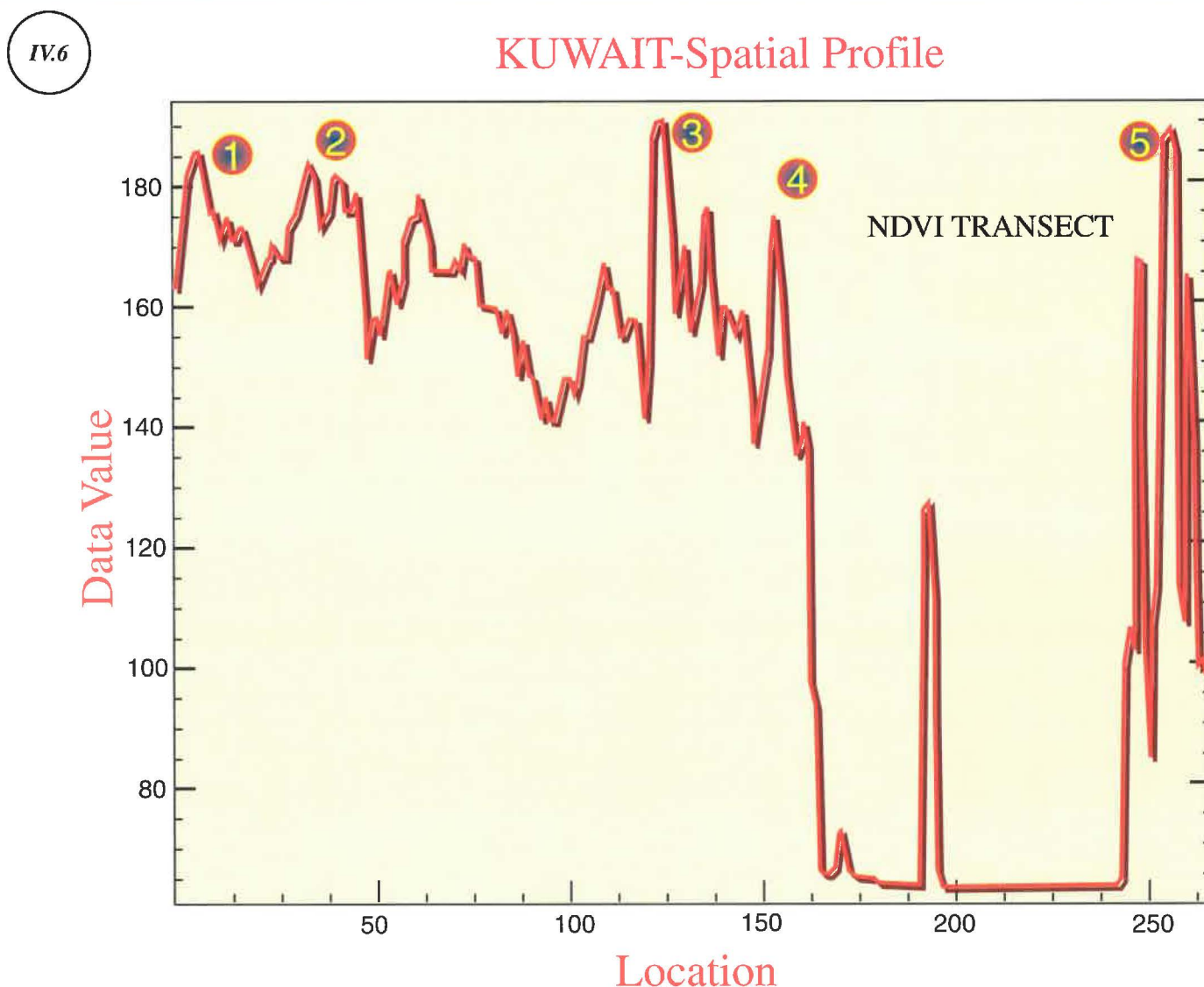
## *Local distribution of vegetation*

VEGETATION INTENSITY, EXPRESSED BY RELATIVE NDVI VALUES IS PLOTTED AGAINST SPATIAL PROFILE, AS SHOWN IN FIGURE IV.6 BELOW. THIS PATTERN OF DATA ANALYSIS IS FOLLOWED THROUGH FIGURE IV.9.

(BELOW): SPATIAL PROFILE OF DISTRIBUTION OF THE NDVI VALUES (VEGETATION) FOR KUWAIT (SEE FIGURE VI.3).

(3) IRRIGATED FARMING - SULAIBIYA, (4) AHMADI, IN THE NORTH - WHITE SPOT IS IRRIGATED FARMING - ABDALI. REFERENCE POINTS OUTSIDE KUWAIT: (1), (2), UN DEMILITARIZED ZONE ROUGH GRAZING / NOMADIC HERDING AREAS, (5) IRRIGATED FARMING, SHATT AL-ARAB.

(SEE FIGURE VI.3 - FROM ASSESSMENT OF INDUSTRIAL AND URBAN HEAT ISLAND EFFECTS). THE NDVI IMAGE OF THE CENTRAL PART OF KUWAIT. (3) IRRIGATED FARMING - SULAIBIYA, (4) AHMADI, IN THE NORTH - WHITE SPOT IS IRRIGATED FARMING - ABDALI. REFERENCE POINTS OUTSIDE KUWAIT: (1), (2), UN DEMILITARIZED ZONE ROUGH GRAZING / NOMADIC HERDING AREAS, (5) IRRIGATED FARMING, SHATT AL-ARAB.





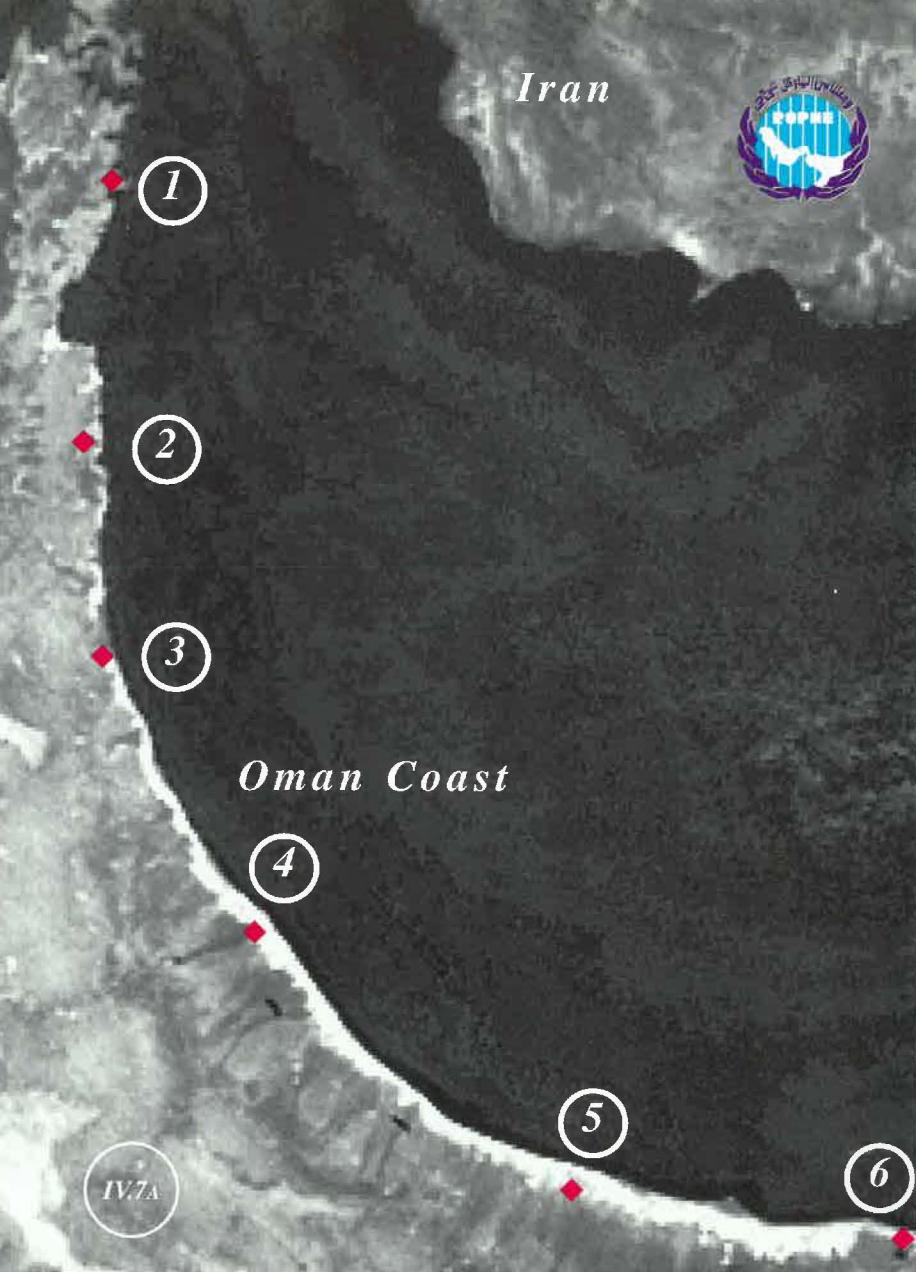


FIGURE IV.7A: THE NDVI SINGLE SCENE IMAGE OF NORTHERN OMAN. SCALAR HIGH CONTRAST IMAGE WITH SPATIAL RESOLUTION: 1KM/PIXEL FROM MARCH 1997. THE IMAGE SHOWS RELATIVELY HETEROGENOUS GROUPING OF VEGETATION ALONG THE COAST, SHOWN IN WHITE.

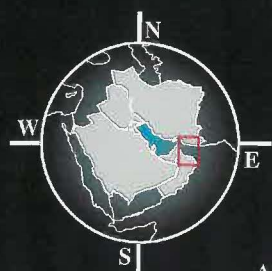
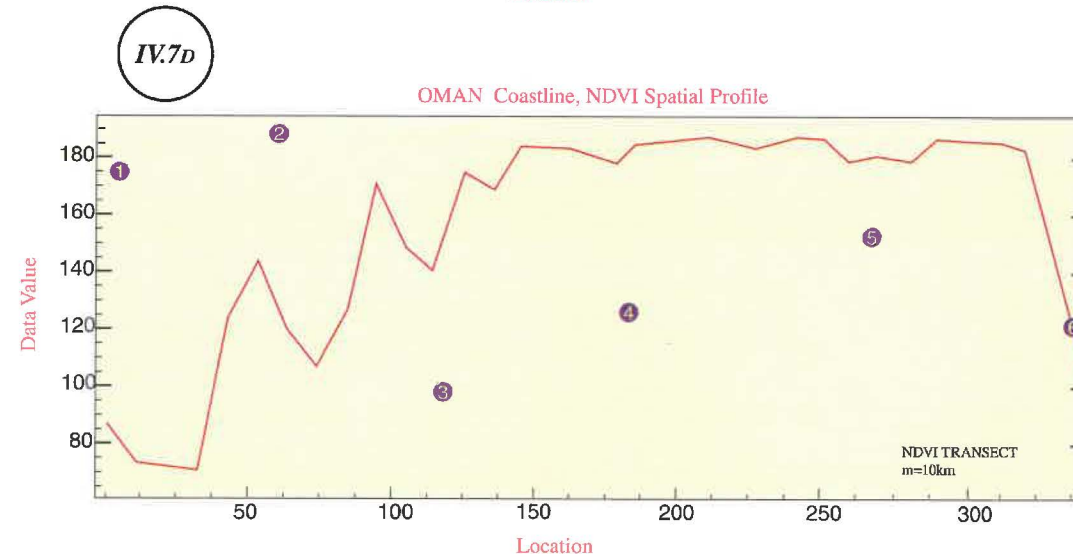
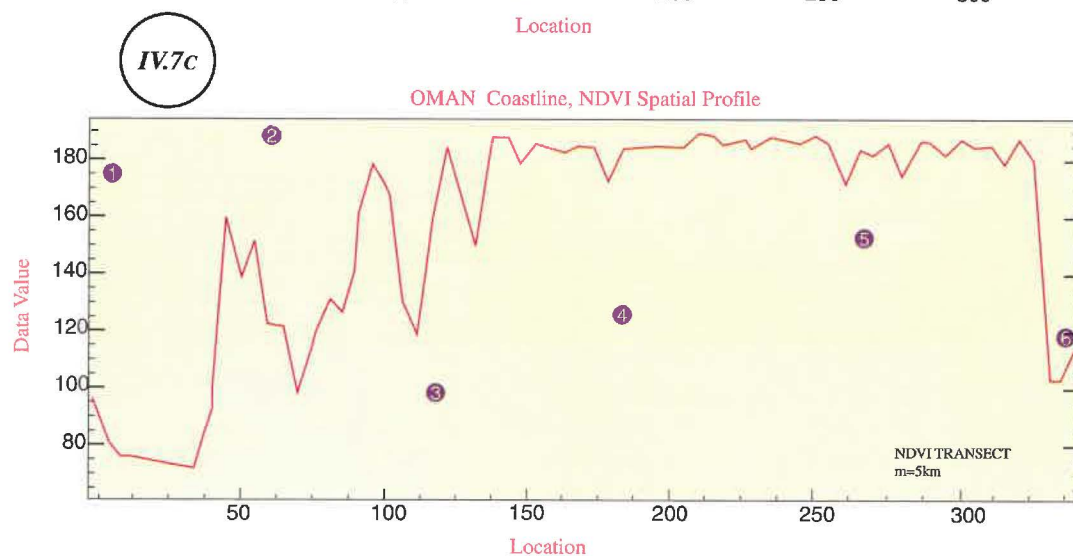
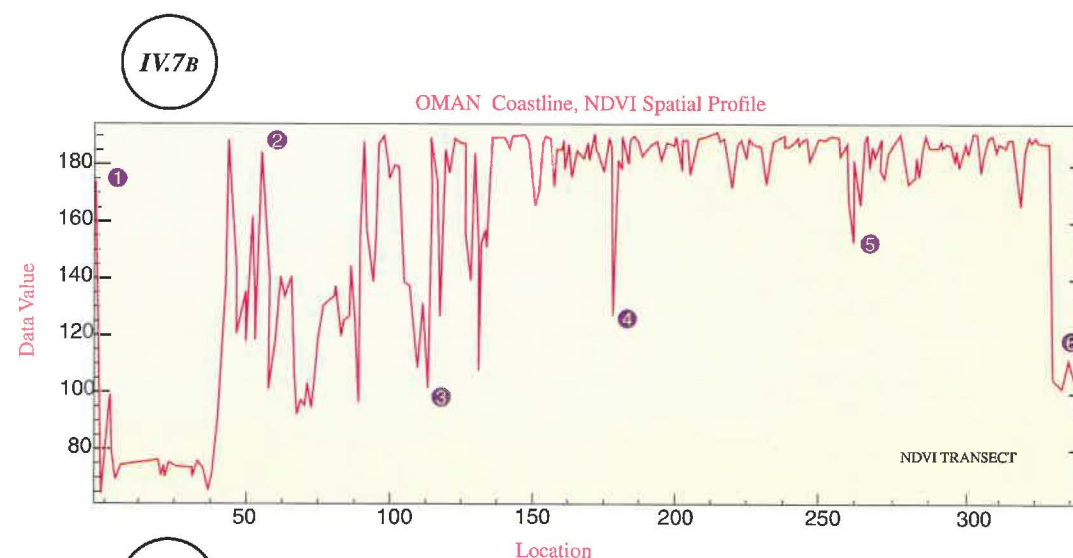


FIGURE IV.7B, C (REGULARIZATION OF CURVE OF DISTRIBUTION OF NDVI, THE AVERAGE INTERVAL IS 5KM), AND D (REGULARIZATION OF CURVE OF DISTRIBUTION OF NDVI, THE AVERAGE INTERVAL IS 10KM). SPATIAL PROFILE OF DISTRIBUTION OF NDVI VALUES FOR VEGETATION AND IRRIGATED FARMING ALONG OMAN'S COASTLINE (SEE FIGURE IV.7A).

# OMAN

## Local distribution of vegetation



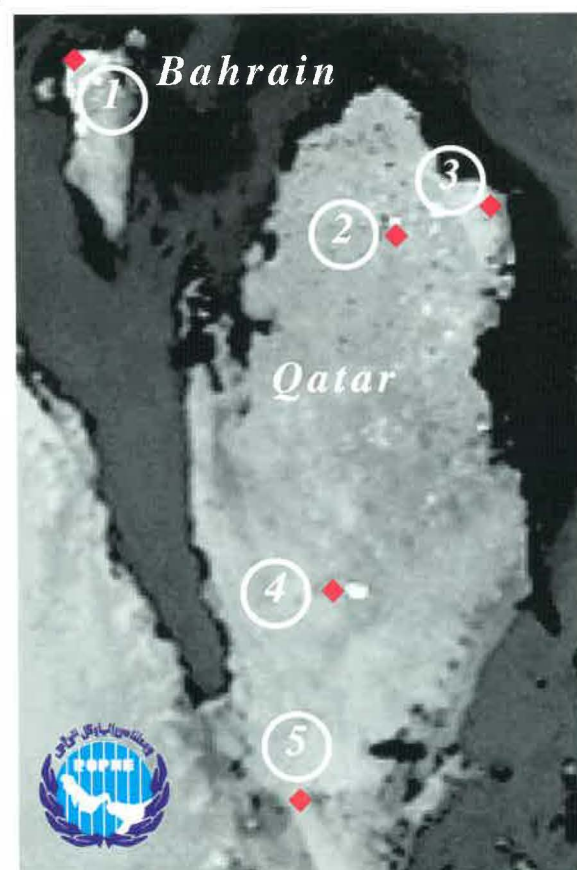


# BAHRAIN & QATAR

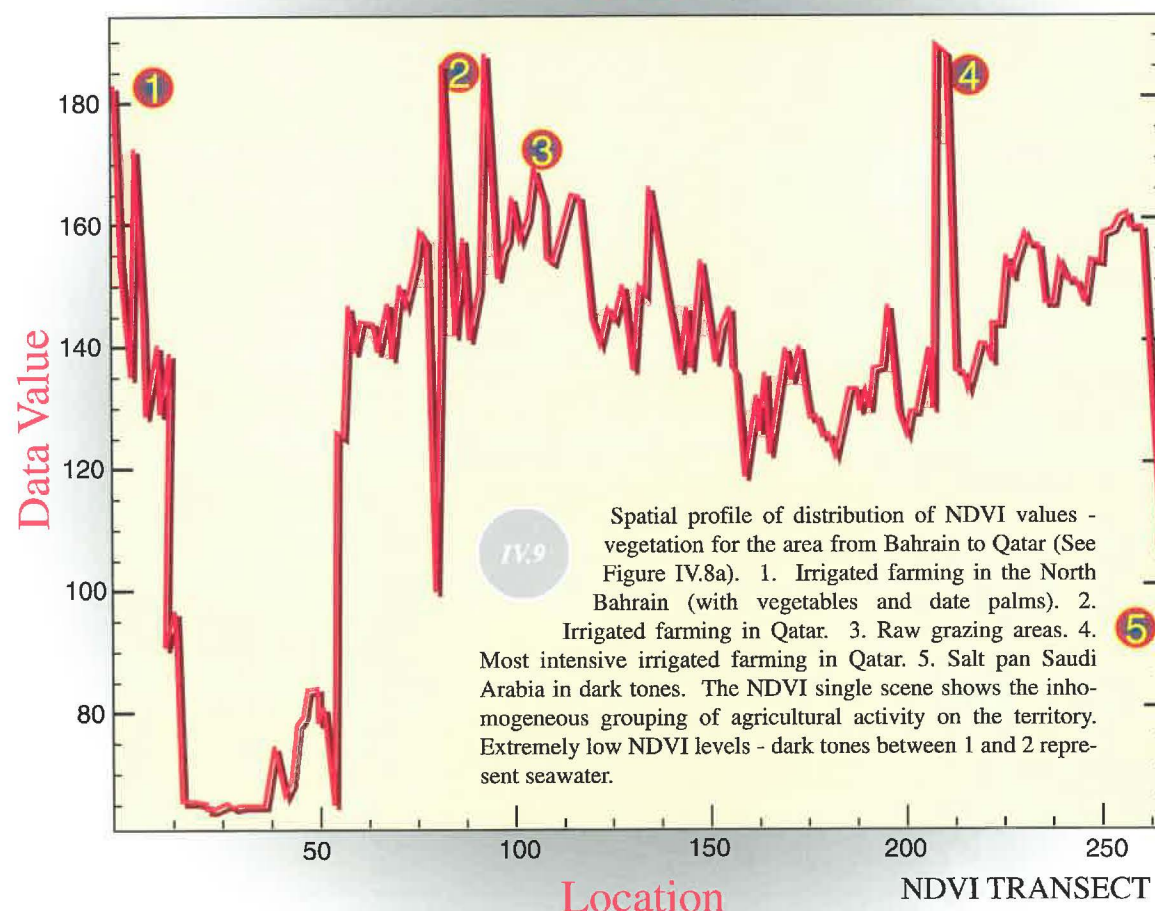
IV.8a The NDVI single scene image of Bahrain and Qatar processed from NOAA / AVHRR. Scalar high contrast image with spatial resolution: 1km/pixel from March 1997. Regional Scale Data.

Irrigated farms in Qatar show rich vegetation with high NDVI (white spots in the image) vegetables, cereals, fruits and fodder. The relatively dark areas represent large wasteland areas. The seawater is black.

In Bahrain, the relatively high values of NDVI correspond to vegetation along the North and North West coastline areas, some of which represent irrigated farming. Urban areas also show high NDVI relating to parks and gardens. Dark grey represents wastelands in Bahrain.



## BAHRAIN/QATAR-Spatial Profile



IV.8a (RIGHT): THE NDVI SINGLE SCENE IMAGE OF BAHRAIN AND QATAR PROCESSED FROM LANDSAT THEMATIC MAPPER TM FROM FEBRUARY 1995. SCALAR IMAGE, NATIONAL SCALE DATA. SPATIAL RESOLUTION: 30M / PXL. THE NDVI IMAGE OF BAHRAIN AND QATAR IN DETAIL. THE IRRIGATED FARMS (RAWDA) IN QATAR APPEAR RICH IN VEGETATION AND HIGH NDVI (LIGHT GREY, GREY-WHITE SPOTS ON THE IMAGE) VEGETABLES, CEREALS, FRUITS, AND FODDER. RELATIVELY DARK AREAS REPRESENT LARGE WASTELAND AREAS. SEAWATER IS IN DARK GREY TONES. THE CORAL REEFS AND SAND BANKS ARE MORE DARK GREY-BLACK. RELATIVELY HIGH VALUES OF NDVI IN LIGHT GREY, GREY-WHITE, ARE SHOWN ALONG THE NORTH AND NORTHWEST COASTLINE, SOME OF WHICH REPRESENT IRRIGATED FARMING. URBAN AREAS ALSO SHOW HIGH NDVI RELATING TO PARKS AND GARDENS. DARK GREY REPRESENTS WASTELANDS IN BAHRAIN. THE CORAL REEFS, ESPECIALLY FASHT AL ADHAM REEF COMPLEX, ARE MORE DARK GREY-BLACK.



# BAHRAIN & QATAR

*Bahrain*

*Qatar*

*Saudi Arabia*





# UNITED ARAB EMIRATES



(RIGHT): THE NDVI SINGLE SCENE IMAGE OF UAE PROCESSED FROM NOAA / AVHRR

SCALAR HIGH CONTRAST IMAGE WITH SPATIAL RESOLUTION: 1KM/PIXEL PROCESSED FROM NOAA / AVHRR FROM MARCH 1997. REGIONAL SCALE DATA.

PALM TREES IN GREEN ON THE IMAGE REPRESENT RELATIVELY HIGHER VALUE OF NDVI (RICH VEGETATION).

IRRIGATED FARMING IS SHOWN AS WHITE SPOTS WITH HIGH NDVI. NEAR THE MAIN ROADS IT IS POSSIBLE TO SEE PLACES OF IRRIGATED FARMING. THE OASES ARE SHOWN AS LIGHTER GREY. ON THE NORTHWEST AND SOUTH (LIWA) THERE ARE SOME DATE PALM TREES CONCENTRATIONS. RELATIVELY DARK AREAS REPRESENT LARGE WASTELAND AREAS; LIGHTER ONES REPRESENT ROUGH GRAZING. SABKHAS MATTI, AND AL SALAMLIA ARE IN DARK TONES WITH LOW NDVI VALUES. SEAWATERS ARE IN BLACK.

RELATIVELY HIGH VALUES OF NDVI ARE SHOWN IN THE SOUTH AND REPRESENT SOME VEGETATION, ROUGH GRAZING, OASES, PALM TREES (SHOWN ON THE IMAGE AS GREEN PALM TREES). THE COASTLINE HAS RELATIVELY LOW NDVI VALUES. SOME OF THE URBAN AREAS, SUCH AS ABU DHABI AND DUBAI SHOW HIGHER VALUES OF NDVI - WHICH REPRESENTS IRRIGATED AGRICULTURE.



IV.11A

CLASSIFICATION OF IMAGE OF ROPME  
SEA AREA SHOWN ON FIGURE IV.2.





IV.11b

MAGNIFICATION OF THE NORTHERN PART OF  
RSA FROM THE CLASSIFICATION IMAGE  
SHOWN ON FIGURE IV.11a.







MAGNIFICATION OF THE WESTERN PART OF  
RSA FROM THE CLASSIFICATION IMAGE  
SHOWN ON FIGURE IV.11A.

IV.11c





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IV.11D

MAGNIFICATION OF THE EASTERN PART OF RSA FROM THE CLASSIFICATION IMAGE SHOWN ON FIGURE IV.11A. THIS RESULT REPRESENTS MAGNIFICATION OF EASTERN PART OF RSA FROM UNSUPERVISED CLASSIFICATION OF THE AVHRR IMAGE SHOWN ON FIGURE IV.2.







IV.11e

FIGURE IV.11e: MAGNIFICATION OF THE SOUTHERN PART OF RSA FROM THE CLASSIFICATION IMAGE SHOWN ON FIGURE IV.11a. THIS RESULT REPRESENTS MAGNIFICATION OF SOUTHERN PART OF RSA FROM HORMUZ STRAIT TO MASIRA ISLAND, UNSUPERVISED CLASSIFICATION OF THE AVHRR IMAGE SHOWN ON FIGURE IV.2.



# LEGEND TABLE

## Seawater



Seawater classes appear in various tones of blue. The patterns of the largest seawater classes in the RSA represent mainly the interaction with the atmosphere.



Rivers plumes and shallow water



Shallow water. Seen in Qatar, UAE and Iran river outfalls.



Deeper, low turbidity waters of Gulf of Oman.

## Clouds

CLOUDS APPEAR IN WHITE ON THE IMAGE



Clouds



THE MAIN LOCATION OF CLOUDS ON THE IMAGE:

- North of the image (South of Iraq and Iran)
- South East of the image (On the Oman coast and Gulf of Oman)
- South West of the image (Saudi Arabia)

## Land surface

Despite the resolution of 1 km per pixel, it is easy to distinguish interaction between various land structures of ROPME Region.



WEST



In the west, the RSA coastland surface mainly has rough grazing / nomadic herding, barren soils, and some coastal urban areas. In some places, rough grazing / nomadic herding areas appear in different colours, due to overgrazing. These areas are located in Kuwait, Saudi Arabia, UAE and Oman.

EAST



In the East, the RSA coast is covered with vegetation, such as pastures and scattered farming woodlands.

Sabkha areas (Marshlands) are characterized by higher humidity.



# LEGEND TABLE

## *Irrigated Farming*

### WEST COAST OF RSA



The irrigated farming agriculture areas, oases, etc. land use classes appear as small dark green spots. The areas are located in Kuwait, Saudi Arabia, Qatar, UAE, the sea coast of North West Bahrain and Oman.



Irrigated farming spots of Central Kuwait (Sulaibiya farms), Central and North East Qatar, and near the channels of Shatt Al-Arab show the highest concentration of bio-mass in the Region.



Beshagrad Mountain chain (in the south-east).



Pastures, together with irrigated farming.



Rough grazing, mainly nomadic herding.



Zohreh, Mond and other river outlets modulate the colour of I.R. Iran north-east coastal waters in relatively small plume patterns.

## *I.R. Iran*

It is easy to distinguish various natural classes of the eastern part of ROPME Region (I.R. Iran) in view of diversity of geomorphological features.



Inland water bodies such as Daryacheh-ye Tashk, Daryacheh-ye Bakhtegan, Daryacheh-ye Maharlu, Daryacheh-ye Parishan / Famir and lakes.



Hamun i Jaz Muriyan marshes (in the south) and marshlands with higher humidity.



Woodland / forests of Zagros Mountain chain.



Snow cover on the Zagros Mountain chain.

## *Sultanate of Oman*



The Irrigated farming in Suhar and Muscat, North coastal area.



Some oases (such as Nizwa) are shown in the Image.



Al Hajar Al Gharbi Mountain chain is mainly rough grazing / nomadic herding.



Barren lands  
It is possible to see abundance of structure types in the barren lands between Oman and Saudi Arabia.



Sabkha areas / Marshlands with higher humidity. Umm as Sumim Sabkha / Marshlands, the same structure appear near Khaluf.





# LEGEND TABLE

## Kingdom of Saudi Arabia



The oases on the West Coast appear as points and spots.



Coastline rough grazing / nomadic herding areas.



In the arid lands on the west with increase of attitude of topography it is possible to follow various types of structures, which represent different landforms.



On the South, barren land areas are divided into large subclasses from west to east which correspond to the specific desert land forms as various type of dunes, etc. features, bordering with UAE and Oman.



## United Arab Emirates



Low topography levels, Sabkha Matti depression, coastal Sabkhas (the same analogy with North of Qatar).



Barrier islands, tidal flats and channels and fringing coral reefs.



Coastal shallow water.



Large linear dunes and sand sheets, well defined lineaments.



Small and mega barchans are represented by spots, near Al Qafa.



North East oases Falaj Al Mualla and on the North from Fujairah.



Main barren land areas.



# LEGEND TABLE

## State of Qatar



Coastal Sabkha is the same as coastal areas in UAE.



Tidal flats, coral reefs.



Irrigated farming appear as points and small spots. The most high-density agriculture spot is in the central part of Qatar.



Barren land.



## State of Bahrain



Irrigated farming appears as patches on the north and west along the coastline.



Tidal flats, coral reefs, especially Fasht Al-Adham reef complex.



Barren land in the central part of the island.



# LEGEND TABLE

## *State of Kuwait*

The borders of the country appear sharp on the surrounding background. The upper surface has a different structure from the surrounding borders. Significant disturbance of natural conditions occurs in the upper surface layers. Changes in the ecosystems (in comparison with those located in the natural environment of the surrounding territory) are expected.



Rough grazing / nomadic herding areas.



Relatively richer rough grazing vegetation in the Kuwait - Iraq border.



Irrigated farming appears as small spots. The highest density agriculture area is in the central part of the country, Sulaibiyah.



Wadi structure, Wadi Al Batin (Kuwait South).



Barren areas, Bubiyan, Sabkha areas.



Shifting sand dunes, strip from North West to South East.



Burgan area, surface contamination disturbs the natural structure of the arid land and creates new structures and new ecosystems that may take over.

## *Republic of Iraq*



Irrigated farming, Shatt Al Arab and canals.



Central part of Al Amarah marshes.



Former marsh areas, Al Amarah marsh (Mesopotamia Marshes).



Sabkha areas / Marshlands with higher humidity.



Flooded area in As Sulaibiyat Depression, Al Hammar, Hawr Al Hawizah water bodies (Mesopotamia Marshes).



East West causeway canal, North - South canal.



Barren area.

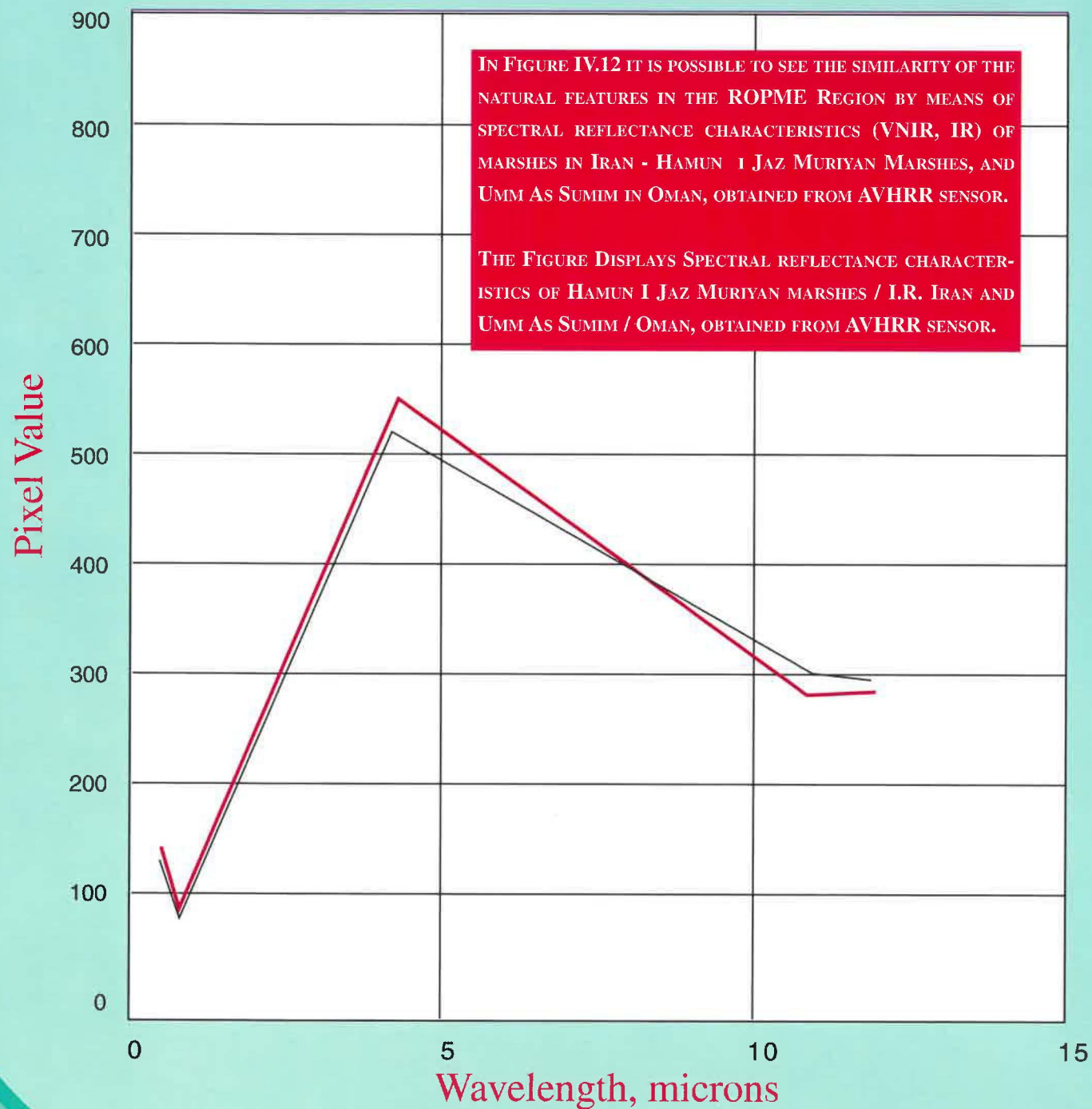


Shallow water and Shatt Al Arab plume in Northern RSA.

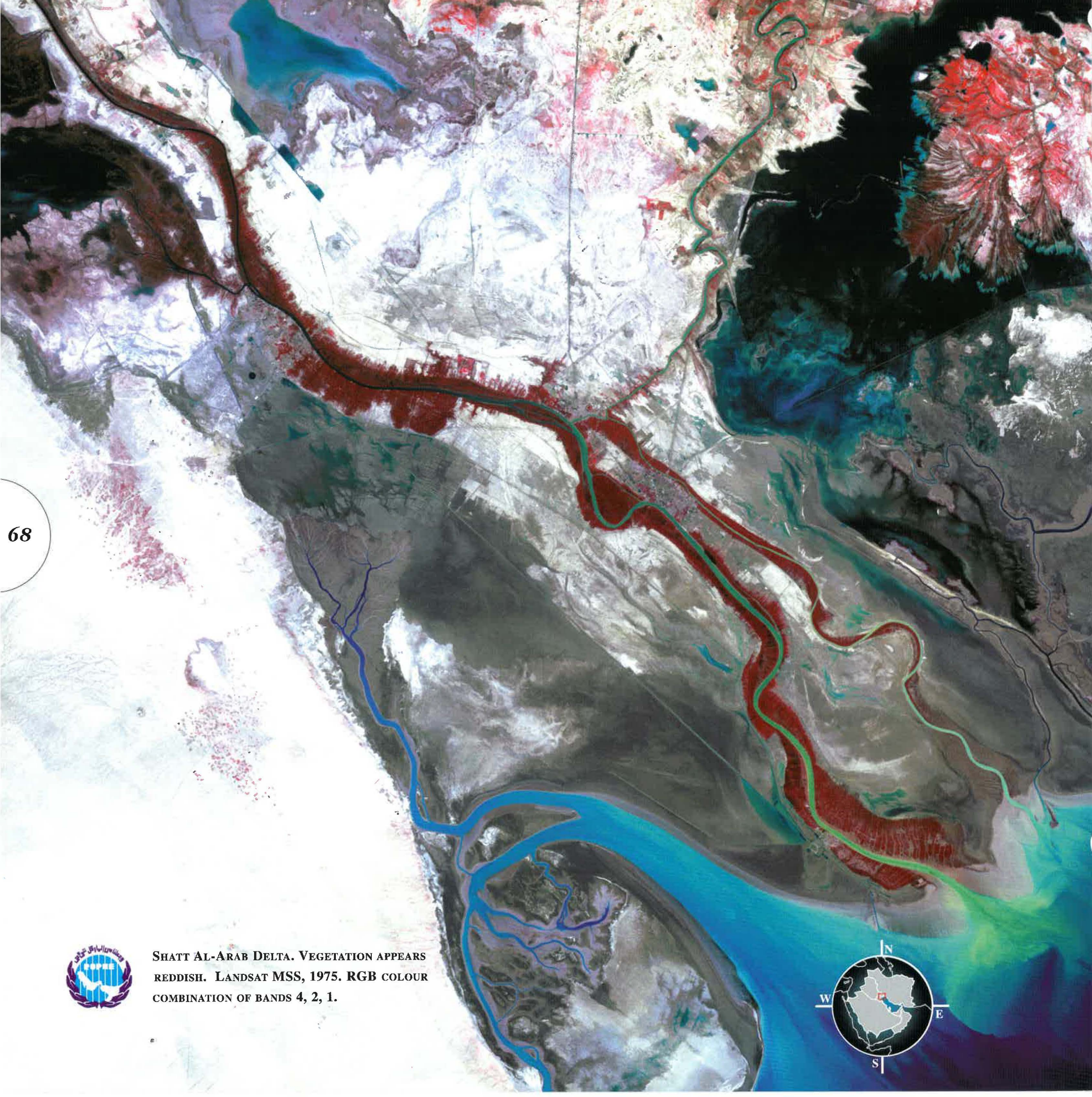


# IDENTIFICATION OF SIMILAR FEATURES

Spectral Profile: Jaz Murian 1, Umm Summim 2, rpm2geo\_cut



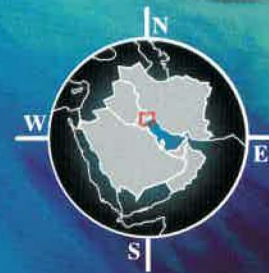




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SHATT AL-ARAB DELTA. VEGETATION APPEARS REDDISH. LANDSAT MSS, 1975. RGB COLOUR COMBINATION OF BANDS 4, 2, 1.





## V. THE MARINE ENVIRONMENT

Examples of images from the marine environment contained in this chapter illustrate the utilization of Remote Sensing orbital platforms for regional monitoring of the marine environment.

RS observations allow us to analyze important characteristics of the marine environment, determine the level of certain pollution phenomena and estimate biological resources for trophic levels ranging from plankton to large fish populations. Seasonal variations in plankton colour are understood along with the analogy of seasonal vegetation changes on land that have been elaborated through space observations.

The biogeochemical cycle on the sea surface plays a significant role in climate change.

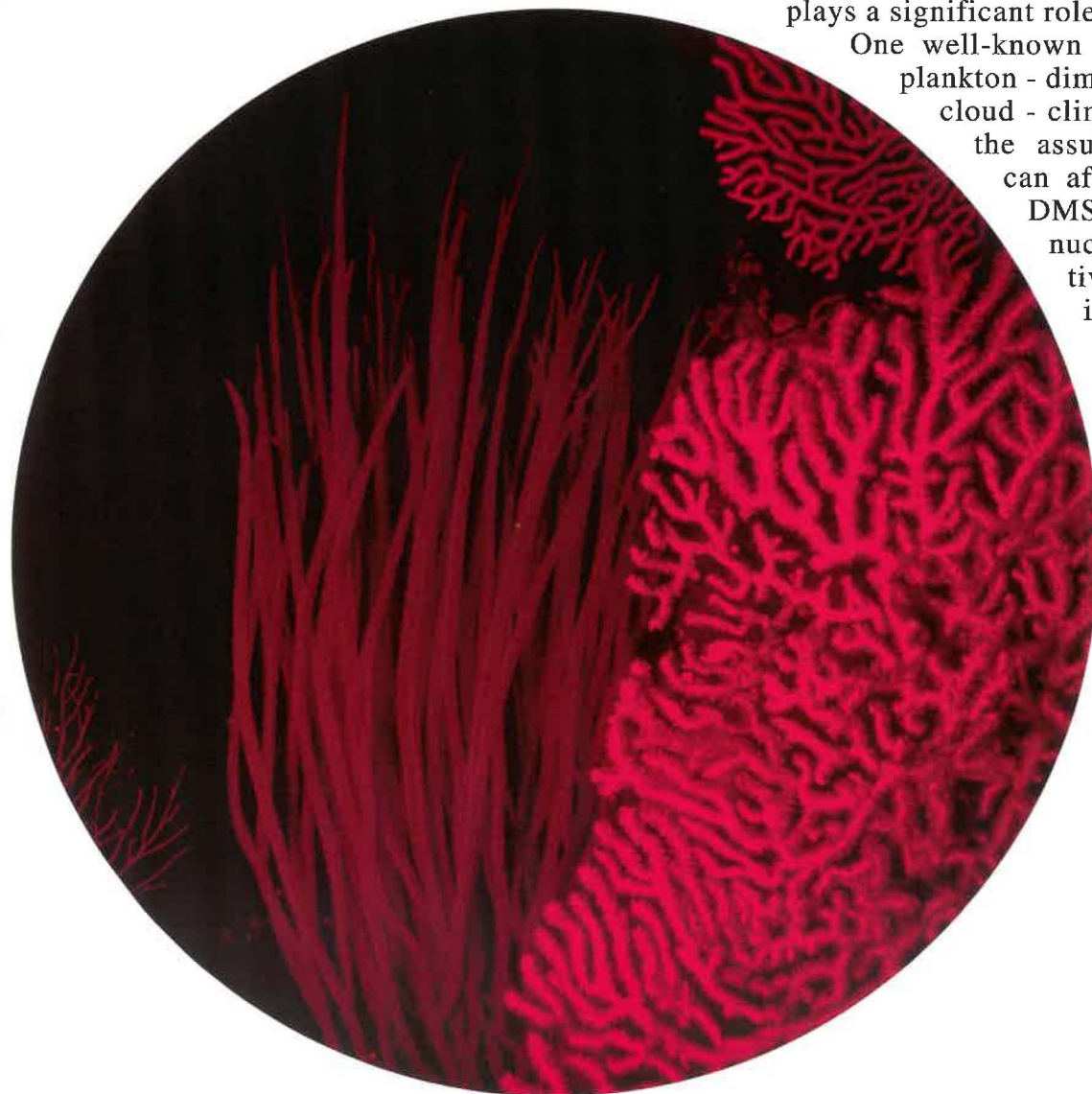
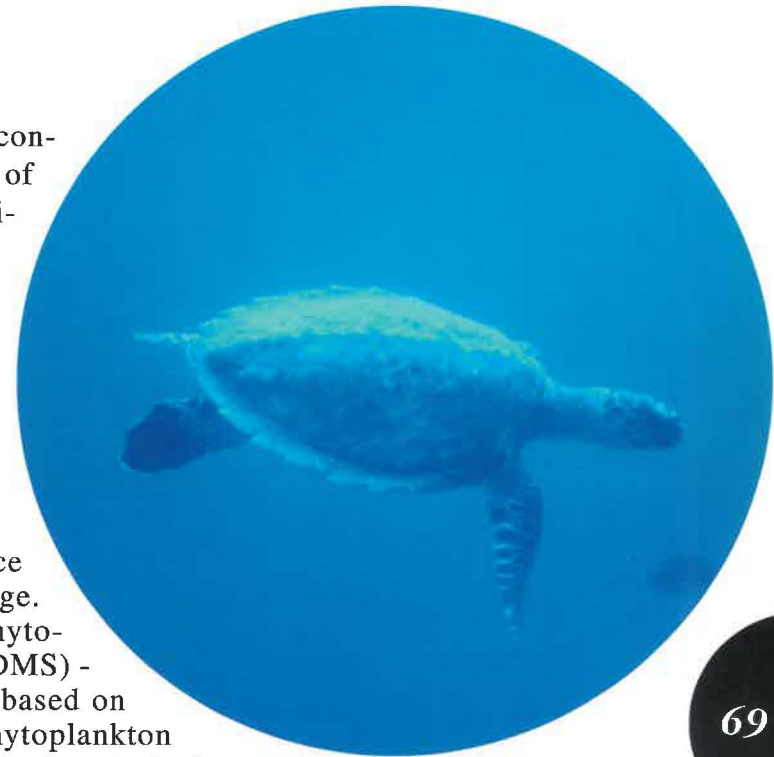
One well-known cycle is the phytoplankton - dimethylsulphide (DMS) -

cloud - climate cycle. It is based on the assumption that phytoplankton can affect cloud albedo by producing

DMS, which is a precursor to aerosols and cloud condensation nuclei and that the cloud albedo could in turn affect the productivity of the phytoplankton, thus creating a climatically significant feedback cycle.

The cloud feedback can be either positive or negative, in influencing the marine surface environment. With the decrease of the falling surface radiance on the sea surface the primary production decreases leading to a decrease in dimethylsulfide, (DMS), produced by marine phytoplankton. This in turn leads to a decrease of aerosols and water droplets responsible for cloud formation.

RS is also useful in monitoring the impact of sea surface temperature (SST), wind speed, salinity and currents on the turbulent heat exchange, weather and climate system.





# SEA CONDITIONS

## *Sea Surface Wind*

Wind is the main driving factor in heat transport and ocean currents. The advanced Wind Scatterometer is to be fixed on Metop series of the polar orbiting meteorological satellites. The data generated will also be of benefit at the regional scale.

## *Sea State and Topography*

Accurate sea surface heights are required for studying ocean dynamic topography, climate, and Global Ocean Circulation Models (GOCM). Since 1975 satellite altimeters have been applied in the study of the geoid and gravity field of the Earth. The NRA/TOPEX satellite altimeter ground track at the equator has a spacing of  $2.835^\circ$  (314km) and an along track sampling rate of 7 km and the sea level measurements have a precision of + 2.4 cm. The synthetic aperture radar (SAR) is used to study the generation and propagation of long ocean waves. The distribution of the short gravity waves, recorded by SAR / SEASAT shows correlation with a number of significantly large-scale phenomena, such as local wind structure, long gravity waves, currents and the local bathymetry. Internal and surface waves have been also studied by LANDSAT / MSS band 7 (0.8-1.1  $\mu\text{m}$ ). The altimeter missions will be continued with Jason-1. The gravity anomaly contour maps have been used for location of hydrocarbon bearing structures. An Earth Explorer Gravity Field and steady state Gravity Circulation Core mission (GOCE), planned for launch from ESA, will continue the studies of the gravity field of the Earth, dynamics of the oceans and interaction with the continents.

## *Salinity*

Salinity and sea surface temperature are the two major climatic factors controlling the circulation of the ocean. LANDSAT / MSS and TM data are used for the retrieval of salinity data of the seawater by applying regression models. Due to the essential impact of clouds on optical remote sensing, the microwave spectral range is used for temperature and salinity retrievals. Passive microwave radiometer at L band (1.43 GHz) and dual frequency microwave radiometer L band and S band (2.65 GHz) have been used for remote sensing of water salinity and temperature with high accuracy.

## *Sea surface temperature*

The sea surface temperature controls air temperature and moisture content and depends on circulation patterns. Satellite observations in atmospheric windows of microwave and infrared spectral ranges are used for SST retrieval. Infrared spectral measurements are with better resolution ( $<1\text{km}$ ), but are affected by atmospheric constituents and clouds. Microwave measurements in spectral range  $>4\text{cm}$  are transparent for clouds, but their resolution is very low. The sea surface temperature defines the heat transport and evaporation, which affects, precipitation and cloud formation. Under clear sky conditions, the observed values of the atmospheric greenhouse effect rise with spatially increasing sea surface temperature at SST above  $298^\circ\text{K}$ . Coupling the predicted sea surface temperature anomalies with GCM allows for evaluating the impact of the sea surface temperature on the weather and climate system. Future AATSR / ENVISAT will allow long term monitoring of the sea surface temperature with an accuracy of less than  $0.5^\circ\text{K}$ .



# OCEAN BIO-OPTICAL DATA

The main RS parameters for fish distribution control are the comfort temperature for each species, and food abundance for that particular type of species. These two main parameters allow us to create highly accurate estimation maps and areas of expectation for sufficient fish species.

## CASE 1 WATERS:

- 1.1 Living algae cells - variable concentration
- 1.2 Associated debris - originating from grazing by zooplankton and natural decay
- 1.3 Dissolved organic matter - (yellow substance) liberated by algae and their debris

## CASE 2 WATERS:

- 2.1 Re-suspended sediments from the sea bottom along the coastline and shallow area
- 2.2 Terrigenous particles - river and glacial runoff
- 2.3 Dissolved organic matter - (terrigenous yellow substance) from land drainage
- 2.4 Anthropogenic influx - particulate and dissolved materials

The colour of the ocean is indirectly related to the chlorophyll concentration, which affects the CO<sub>2</sub> exchange and global climate.

In general, (Morel, 1991), ocean waters are divided into two cases:

**Case 1** are the waters for which phytoplankton and their by-products play the dominant (and presumably exclusive) role in determining the optical properties of the water. The by-products (1.2 and 1.3) include detrital particles (coloured) and yellow substances. These waters range from oligotrophic (very low pigment concentration) to eutrophic waters (with very high pigment concentration).

**Case 2** - are waters where any of substances 2.1 2.2, 2.3, 2.4 are present. This case is usually observed near shores.

Remote sensing of the phytoplankton and primary production is important to evaluate the impact of DMS on climate change and for fisheries. Fish distribution is controlled by temperature and food abundance, which allows for the creation of maps of fish distribution in ocean. Satellite multispectral images (CZCS, SeaWiFS, AVHRR, TM) are used for estimation of sea surface phytoplankton, suspended particles and primary production.

In general, RS observation of seawater is not the only instrument for the analysis of existing processes, but it also has a unique ability to reveal and generalize new phenomena (according to their content of dissolved and suspended matter).



# COASTAL ZONE COLOUR SCANNER

## CZCS OBSERVATIONS OF RSA

The observations from the CZCS radiometer on NIMBUS - 7 satellite took place from 1978 - 1986. These were the first automatic regular observations of the ocean's physical parameters in the visible range of light spectrum. The main colour characteristics of the sea surface were collected. Using digital image processing, a scientific foundation for the new generation of satellite ocean colour sensors (e.g. SeaWiFS) was created. In the future, sea surface phytoplankton and chlorophyll concentrations will be retrieved from MODIS / NASA and MERIS / ENVISAT / ESA data sets.

The CZCS data examples in this study just show the approach for the utilization of orbital platforms for regional sea surface monitoring, and demonstrate the applicability of the satellite multispectral images for environmental monitoring of ROPME sea area.

**FIGURE V.1A:** (OPPOSITE PAGE) CURRENT JETS AND ATMOSPHERIC INFLUENCE IN THE ROPME REGION (HORMUZ STRAIT, UAE AND OMAN COAST).

RGB COLOUR COMPOSITION OF CH3, CH2, AND CH1 OF CZCS / NIMBUS 7 IMAGE FROM DECEMBER 1978 WITH RESOLUTION 1KM / PXL IN THE ROPME REGION COVERING HORMUZ STRAIT, UAE AND OMAN COAST IS SHOWN.

Changes in the water due to chlorophyll concentration and currents are seen in the above figure, as the first 2 channels are sensitive to the phytoplankton in the water. The current jet through Hormuz Strait is seen in the deeper water. Significant atmospheric influence, together with better water penetration in the short wavelengths, is typical of the visible channels in the above image. Atmospheric correction of the satellite data is required for quantitative estimation of the surface and atmospheric variables.

**FIGURE V.1B:** (OPPOSITE PAGE) SHALLOW WATER

BETWEEN QATAR AND UAE, (IN GREEN). MOUNTAIN CHAINS AL HAJAR AL GHARBI AND BESHAGRAD, IN RED.

RGB COLOUR COMPOSITION OF CH4, CH2 AND CH1 OF THE ABOVE IMAGE FROM CZCS / NIMBUS 7 IN THE SAME REGION IS SHOWN.

For bathymetric studies, this composition gives good results. Shallow waters in green are seen between Qatar and UAE. On the land surface, the mountain chains in red appear as follows:

Oman: Al Hajar Al Gharbi Mountain chains  
South Iran: Beshagrad Mountain chains

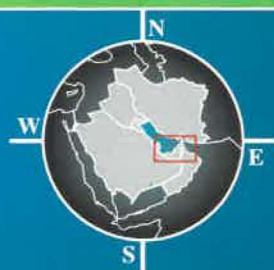
**FIGURE V.1C:** (OPPOSITE PAGE) DETAILED COASTLINE AND BARRIER ISLANDS IN UAE. DETAILS OF MOUNTAIN CHAINS.

RGB COLOUR COMPOSITION OF CH6, CH5, AND CH4 OF THE ABOVE IMAGE FROM CZCS / NIMBUS 7 IN THE SAME REGION IS SHOWN.

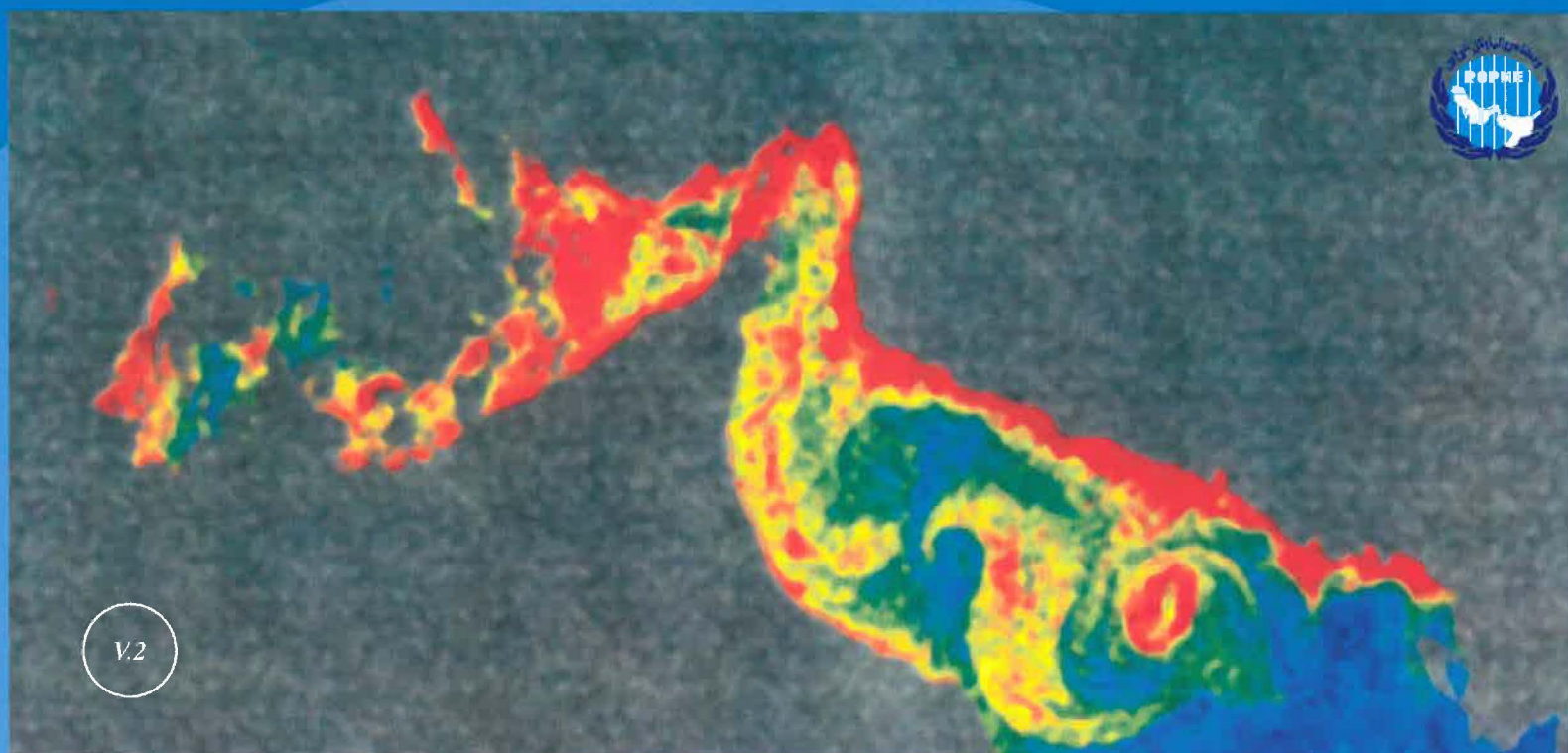
This product could be used for cloud identification. Clouds are shown in yellow and pink. Water appears in red and land surface in green / blue, which shows a detailed coastline. Details of the mountain chains in Oman (Al Hajar Al Gharbi) and south Iran (Beshagard Mountain chains) appear very sharp. Atmospheric influence decreases significantly. The precise shape of the small island groups is visible.

The crossing of Nimbus 7 over the equator at noontime caused the saturation of the visible spectral channels over the lands. That saturation, together with the little sensitivity of TIR CZCS channel to the changes in the chlorophyll concentration in the water, caused colour composition of ch6, ch5, and ch4 to be inappropriate for marine studies. On the same image are details of south Iran woodland and rough grazing / nomadic herding and Oman mountain land use; rough grazing / nomadic herding and irrigated farming.









**F** Figure V.2 displays the Distribution of phytoplankton concentrations. Image retrieved from CZCS in the ROPME Sea Area from April 1986 with resolution 4 km / pxl is shown.

A contrast in the concentration of plankton systems in the south - eastern part of RSA / Gulf of Oman is observed. Clusters of plankton are also produced by the dynamics of the ocean, as seen in the vortex. Red corresponds to higher plankton concentration. Blue shows lower levels.



Present assessment of global primary productivity is based on an aggregation of accidentally located and timed ship observation scans over many decades. It is impossible to resolve time-dependent global changes from this data set. Moreover, current estimates of mean annual productivity vary by more than a factor of two. However, satellite observations eliminate some of the important sampling problems inherent in traditional ship-based oceanography, such as the long interval (compared to typical ocean-dynamic time scales) between observations at different locations. For example, a minute's satellite scene (regional observation system, NOAA / Nimbus type) contains 1 million pixels that cover an area of 1 million square kilometers; it would take more than 67 months for a ship travelling at 20 km/hr to sample each square kilometer .

The use of satellite ocean-colour imagery to estimate primary-productivity for relatively large areas of the seacoast is therefore an attractive alternative. In this approach, satellite estimates of near-surface chlorophyll provides an initial estimate of phytoplankton biomass. The measurements or estimations of other variables affecting primary productivity, such as water temperature and sunlight intensity, can be provided by remote sensing data as well. Model predictions of daily primary productivity are then used to calculate the potential cumulative increase in phytoplankton biomass from the time of the initial biomass estimate until the next available satellite image.



# COASTAL FEATURES OF RSA AS VIEWED BY AVHRR

AVHRR / NOAA gives valuable information for monthly, seasonal and annual variations of the SST, turbidity, diffuse coefficient of photosynthetic available radiation, attenuation coefficients, pigment / phytoplankton concentration, aerosol distribution, land surface variables (albedo, temperature, vegetation cover) and cloud formation.

A strong relationship exists between the optical properties of seawater and its algal biomass content. Clear seawater in satellite images appears deep blue with high reflectance in the 400 - 500 nm range, which results from the combined effect of low absorption coefficient in this spectral range and the back scattering coefficient, which increases towards short wavelengths. In case 1 waters, when phytoplankton concentration increases, a minimum reflectance appears progressively at about 440 nm, which corresponds to the maximum of pigment absorption. A peak in the red (at about 685 nm) spectral range appears due to the fluorescence of chlorophyll-a.

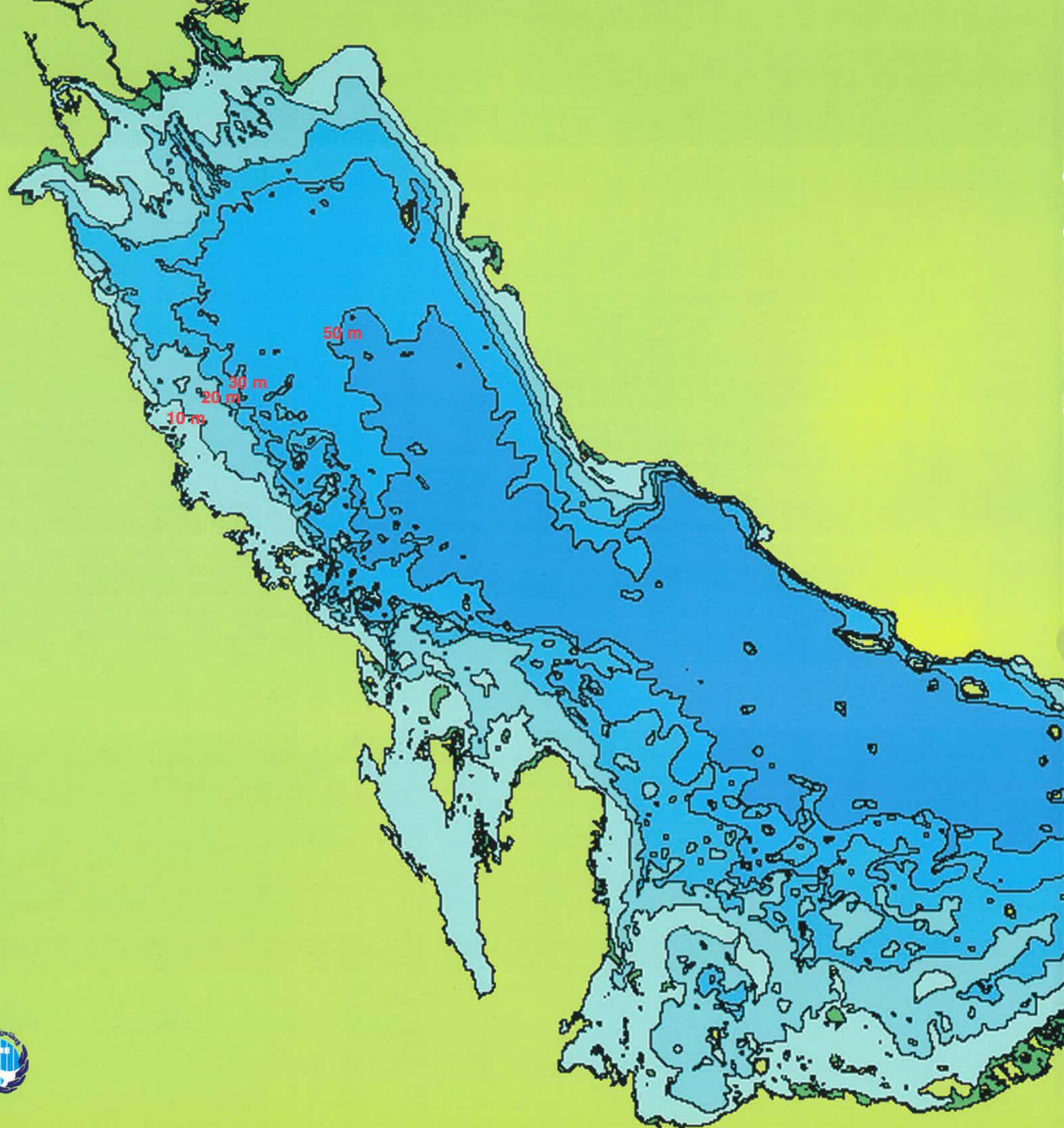
From the distribution of scattering coefficients in the ROPME Sea Area waters, derived from NOAA - AVHRR for June, 1995 (Fig V.4a) it can be seen that the coastal waters of the RSA are eutrophic, with high pigment concentrations and belong to case 2 waters, where the phytoplankton content from June to October increases. Pigment distribution in the Northern and Northeastern coasts of the RSA (Fig V.4a) influenced from Shatt Al-Arab and other small rivers. These rivers together represent the principle source of fresh water discharge into the RSA. The Shatt Al- Arab plume extends into a large area in the North coastal shallow waters (Fig V.4b). The concentration of pigment / phytoplankton increases in the Northern part and in the UAE waters of the inner RSA at the end of October 1995 (Fig V.4c). In the same time SST decrease in the same area (Fig V.5c).

The waters along the eastern part of inner RSA belong to oligotrophic waters, with more than 20 times less pigment concentration.

However, this situation may have changed since 1995 as images taken in 1999 and 2000 reveal greater chlorophyll concentration in the RSA, especially in the Northern sector.

**FIGURE V.3: BATHYMETRIC MAP OF THE ROPME SEA AREA (SEE NEXT TWO PAGES).**







# ROPME

RSA UP TO OMAN

# REGION



V.3

A BATHYMETRIC MAP OF THE ROPME SEA AREA



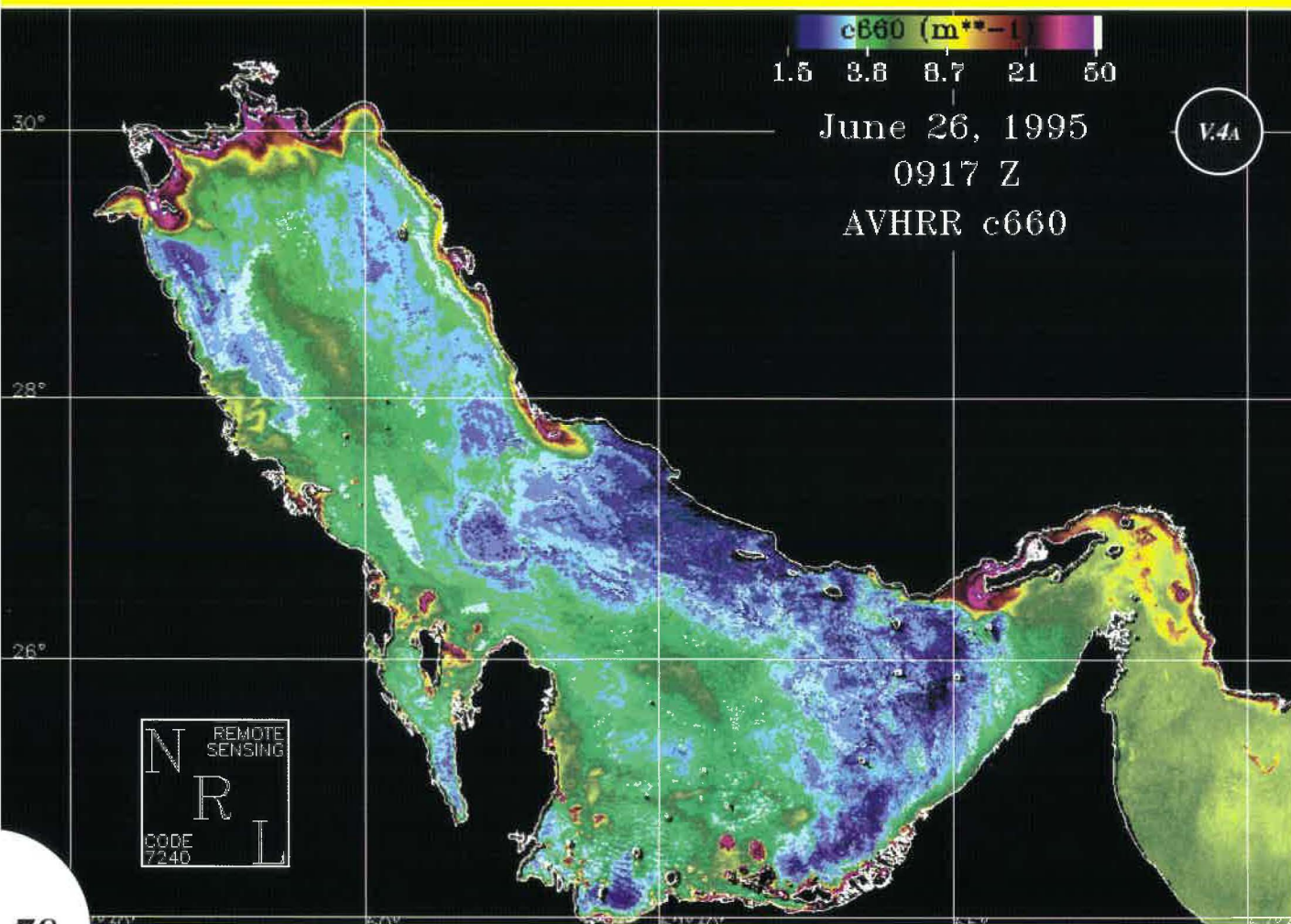


FIGURE V.4A: DISTRIBUTION OF PIGMENTS CONCENTRATION IN THE ROPME SEA AREA. JUNE 1995, RETRIEVED FROM NOAA / AVHRR.

RESOLUTION 1 KM / PXL. PURPLE, MAGENTA, AND REDDISH CORRESPOND TO THE HIGHER CONCENTRATIONS, GREENISH - BLUE TO THE LOWER ONE, (NRL).

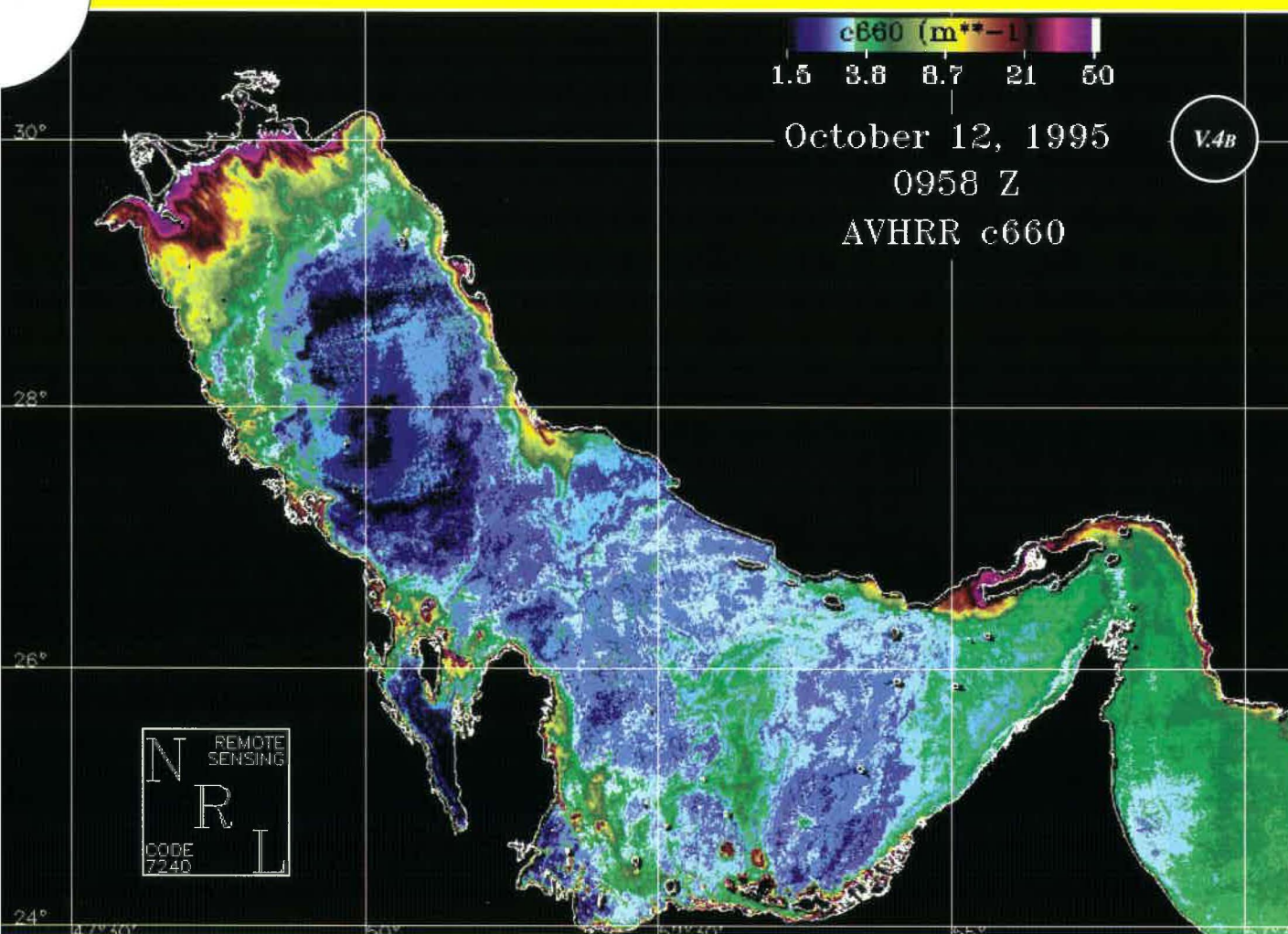
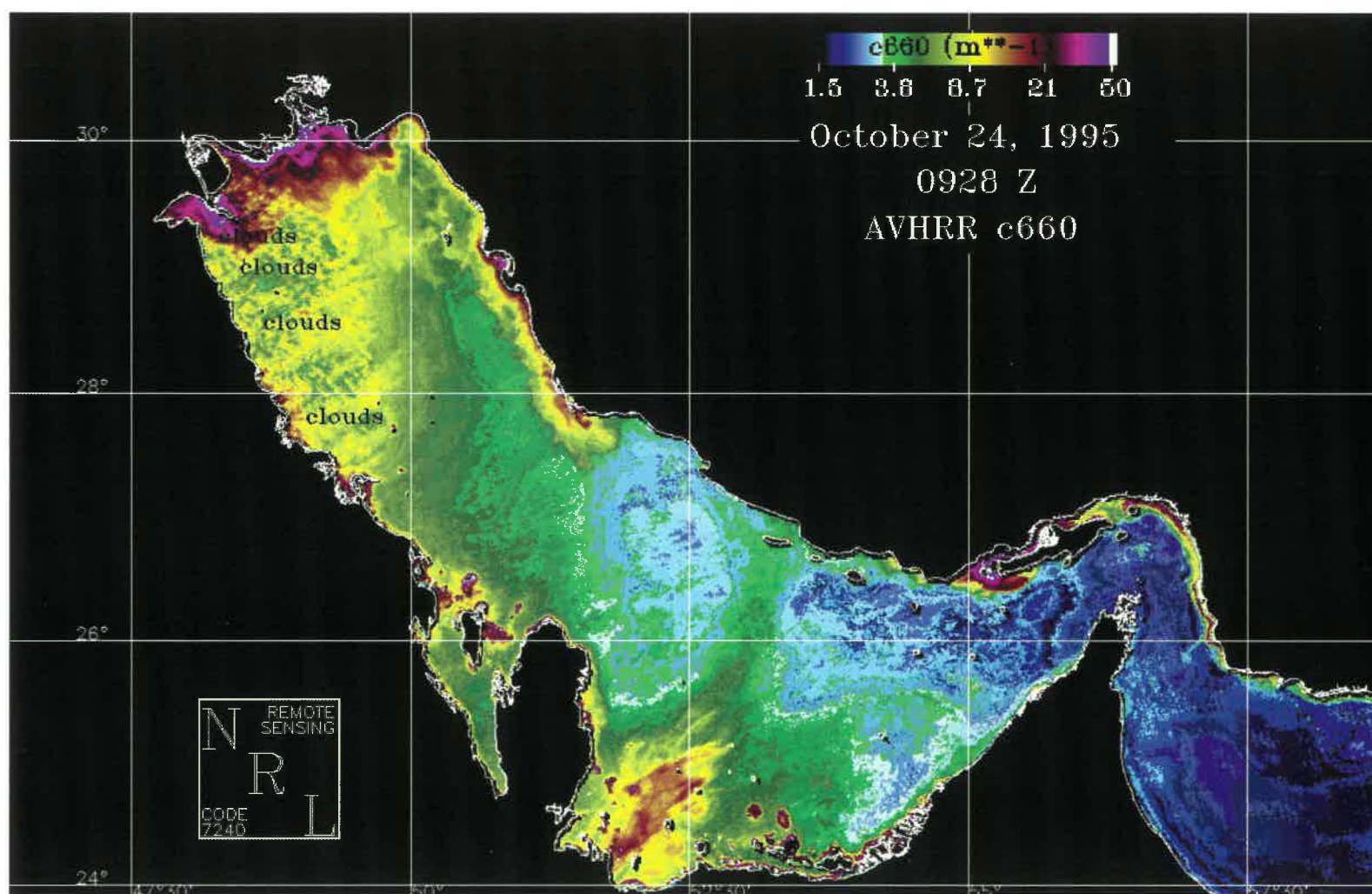


FIGURE V.4B: DISTRIBUTION OF PIGMENTS CONCENTRATION IN THE ROPME SEA AREA. MID - OCTOBER 1995, RETRIEVED FROM NOAA / AVHRR.

RESOLUTION 1 KM / PXL. PURPLE, MAGENTA AND RED CORRESPOND TO THE HIGHER CONCENTRATIONS, GREENISH - BLUE TO THE LOWER ONES, (NRL).





V.4c

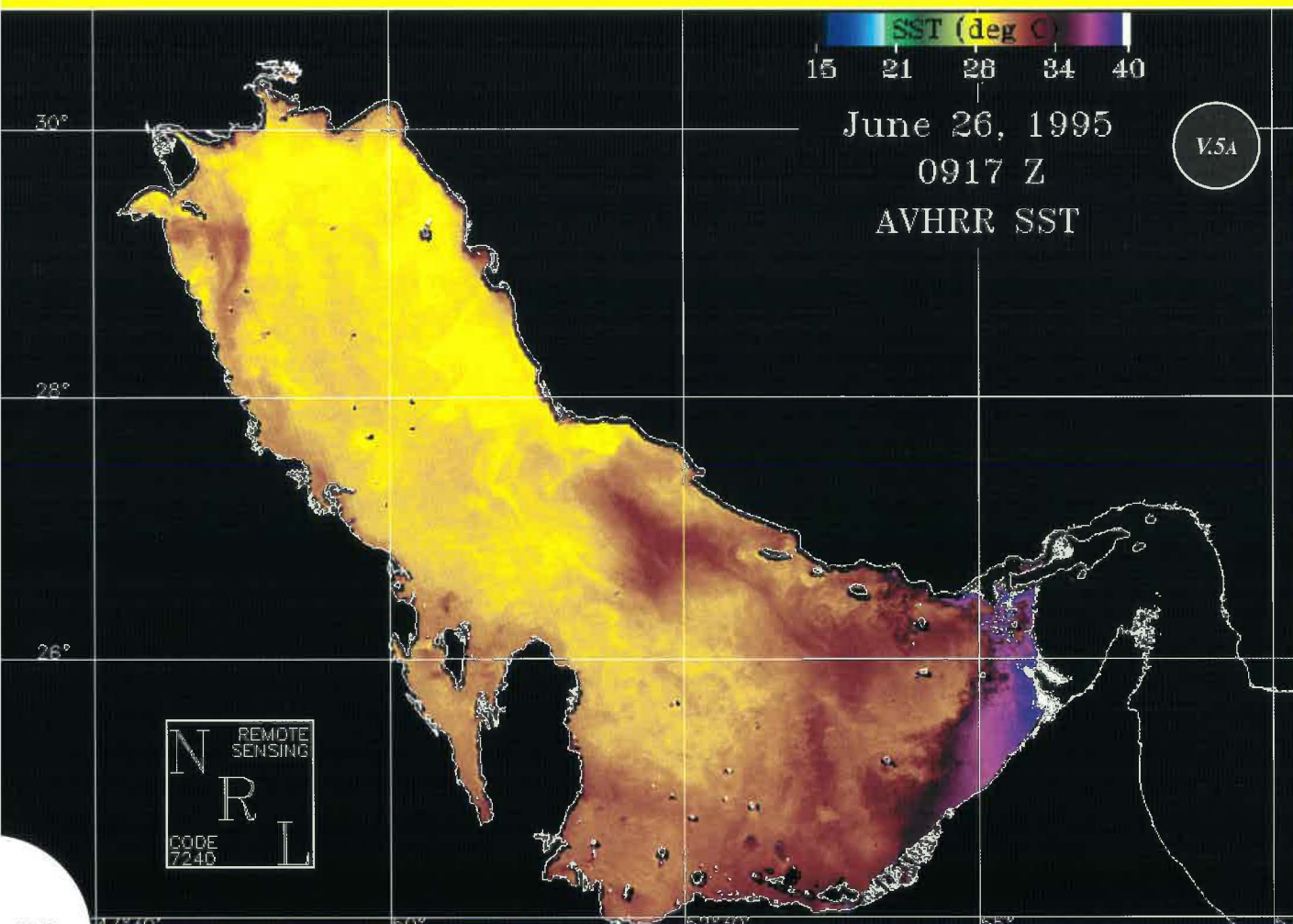
**DISTRIBUTION OF PIGMENTS CONCENTRATION IN THE ROPME SEA AREA. END OF OCTOBER 1995, RETRIEVED FROM NOAA / AVHRR.**

**RESOLUTION 1 KM / PXL. PURPLE, MAGENTA AND RED CORRESPOND TO THE HIGHER CONCENTRATIONS, GREENISH - BLUE TO THE LOWER ONES. SMALL INFLUENCE OF CLOUDS IS PRESENT IN THE NORTHWEST PART OF RSA, (NRL).**

In the southern part of Inner RSA, the shallow coastal waters that border Qatar and UAE (Figure V.4c), support rich fauna and stimulate plumes of plankton - rich water. The same is valid for the eastern part of Qeshm Island in Iran, and the coral reefs areas around Bahrain and the Abu Ali area in Saudi Arabia. Reddish - brown colours border the productive coastal waters in the northern and southern part of RSA.



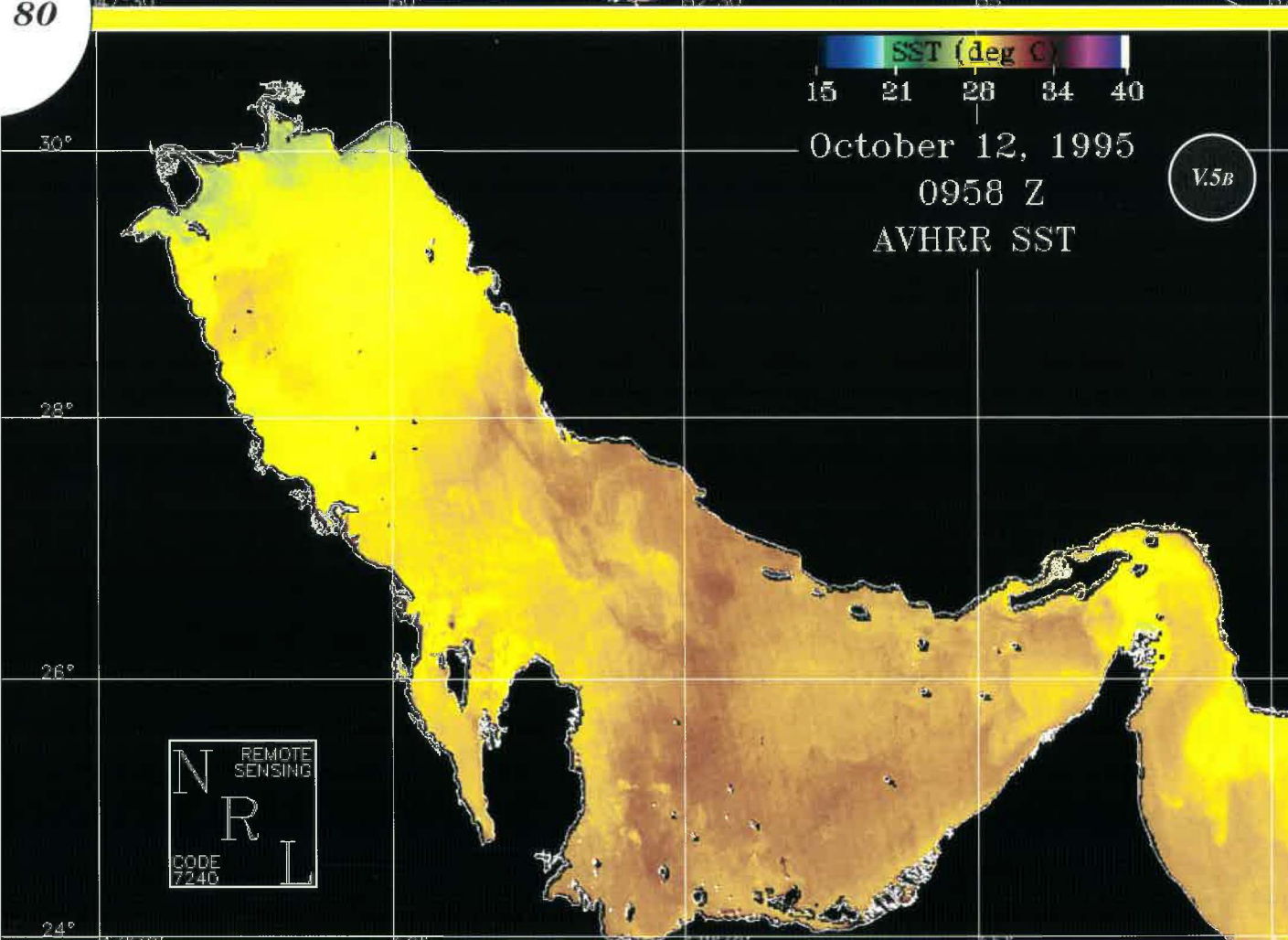




**FIGURE V.5A: SEA SURFACE TEMPERATURE DISTRIBUTION IN THE INNER ROPME SEA AREA IN JUNE 1995, RETRIEVED FROM NOAA / AVHRR.**

**RESOLUTION 1 KM / PXL. REDDISH - PURPLE COLOURS CORRESPOND TO HIGHER SURFACE TEMPERATURE, YELLOW - TO LOWER ONES, (NRL).**

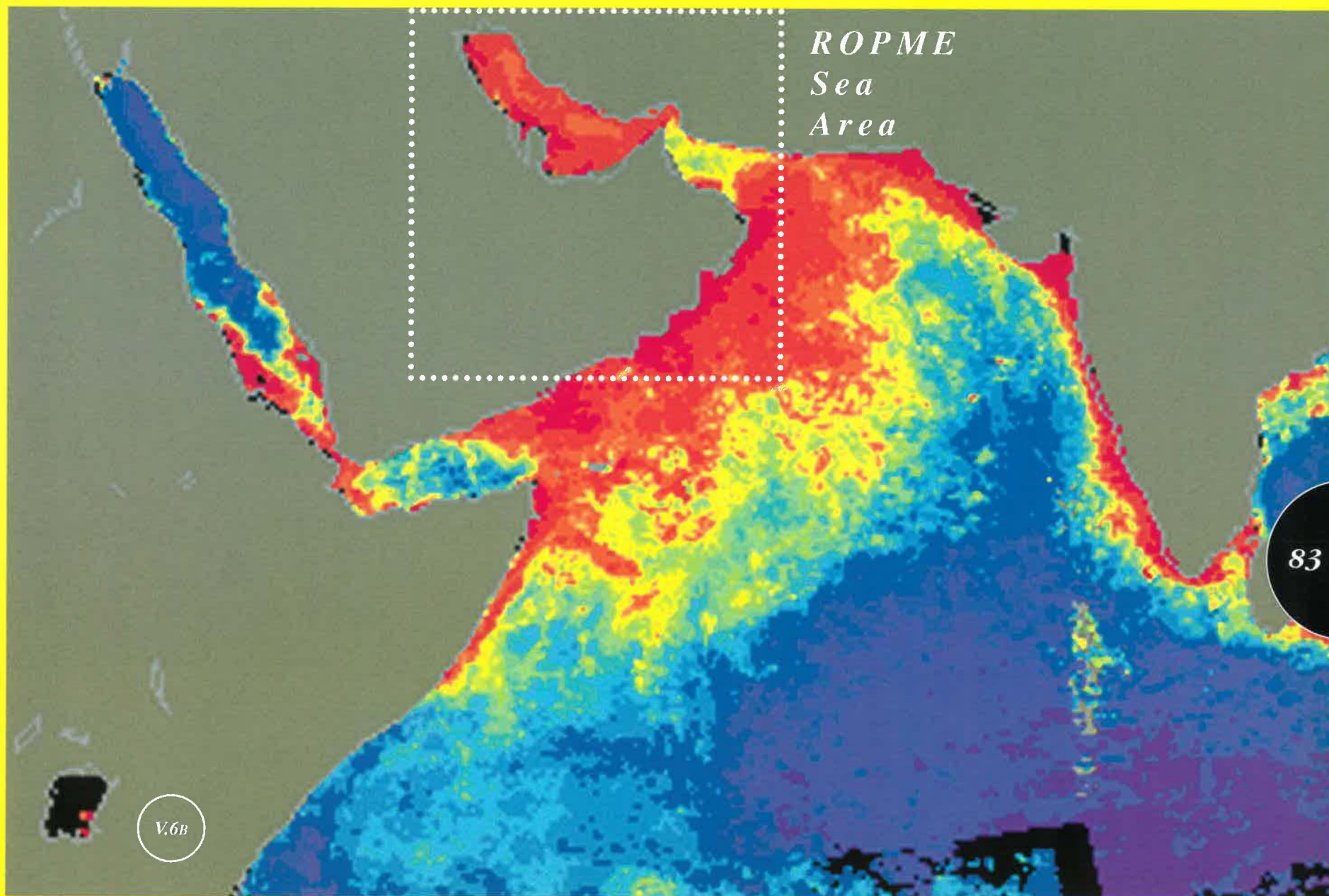
The south - eastern part of Inner RSA shows a relatively higher temperature distribution (specifically shallow coastal waters in UAE and South Iran coast and more shallow western coast).



**FIGURE V.5B: SEA SURFACE TEMPERATURE DISTRIBUTION IN THE ROPME SEA AREA IN MID - OCTOBER 1995 RETRIEVED FROM NOAA / AVHRR.**

**RESOLUTION 1 KM / PXL. RED CORRESPONDS TO HIGHER SURFACE TEMPERATURE, GREENISH-YELLOW - TO THE LOWER ONES, (NRL).**





**FIGURE V.6B: DISTRIBUTION OF PHYTOPLANKTON IN THE INDIAN OCEAN IN SUMMER.**  
**LOW-RESOLUTION COMPOSITE IMAGE IN SEPTEMBER-OCTOBER OF THE INDIAN OCEAN, CZCS DATA SET. THE INFLUENCE OF THE INDIAN OCEAN IN SUMMER ON THE PHYTOPLANKTON CONCENTRATION IN THE ROPME SEA AREA IS OBSERVED.**

**(LEFT) FIGURE V.6A: DISTRIBUTION OF PHYTOPLANKTON IN THE INDIAN OCEAN IN SPRING.**  
**LOW-RESOLUTION COMPOSITE IMAGE IN MAY-JUNE OF THE INDIAN OCEAN, CZCS DATA SET. THE INFLUENCE OF THE INDIAN OCEAN IN SPRING ON THE PHYTOPLANKTON CONCENTRATION IN THE ROPME SEA AREA IS OBSERVED.**



# LOCAL DISTRIBUTION OF PIGMENT / PHYTOPLANKTON CONCENTRATION



FIGURE V.7A. DISTRIBUTION OF PIGMENTS CONTENTS NEAR THE UAE COAST.

Scalar high contrast image with spatial resolution 1 km / pxl from RSA, UAE coast, 1995, retrieved from NOAA / AVHRR data. Light tones correspond to higher pigment concentration, dark tones - to lower. The image shows high concentrations of pigment contents along the coast and around the islands.



Higher pigment concentration is represented as bright spots on the image.

FIGURE V.7B. THE PLOT OF PIGMENTS CONCENTRATION NEAR THE UAE COAST IS SHOWN (1995) ALONG THE TRANSECT FROM FIGURE V.7A

The concentration of pigment increases around the island of Qeshm with the increase of data value (y axis). The location is shown in relative units between the points. Sampling interval is 1 km.

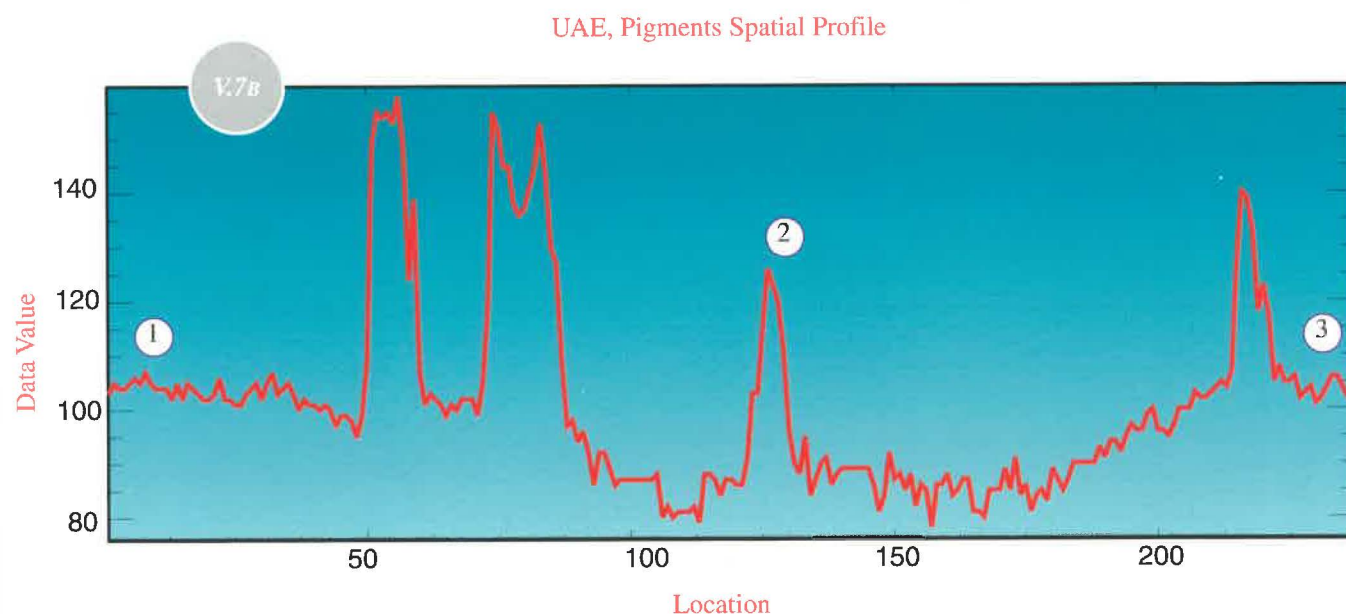




FIGURE V.7C: THE PLOT OF PIGMENTS CONCENTRATION NEAR THE UAE COAST IS SHOWN ALONG THE TRANSECT FROM FIGURE V.7A

Regularization of the curve of distribution, the average interval is 5 km. The concentration of pigment increases with the increase of data value (y axis). The location is shown in relative units between the points.

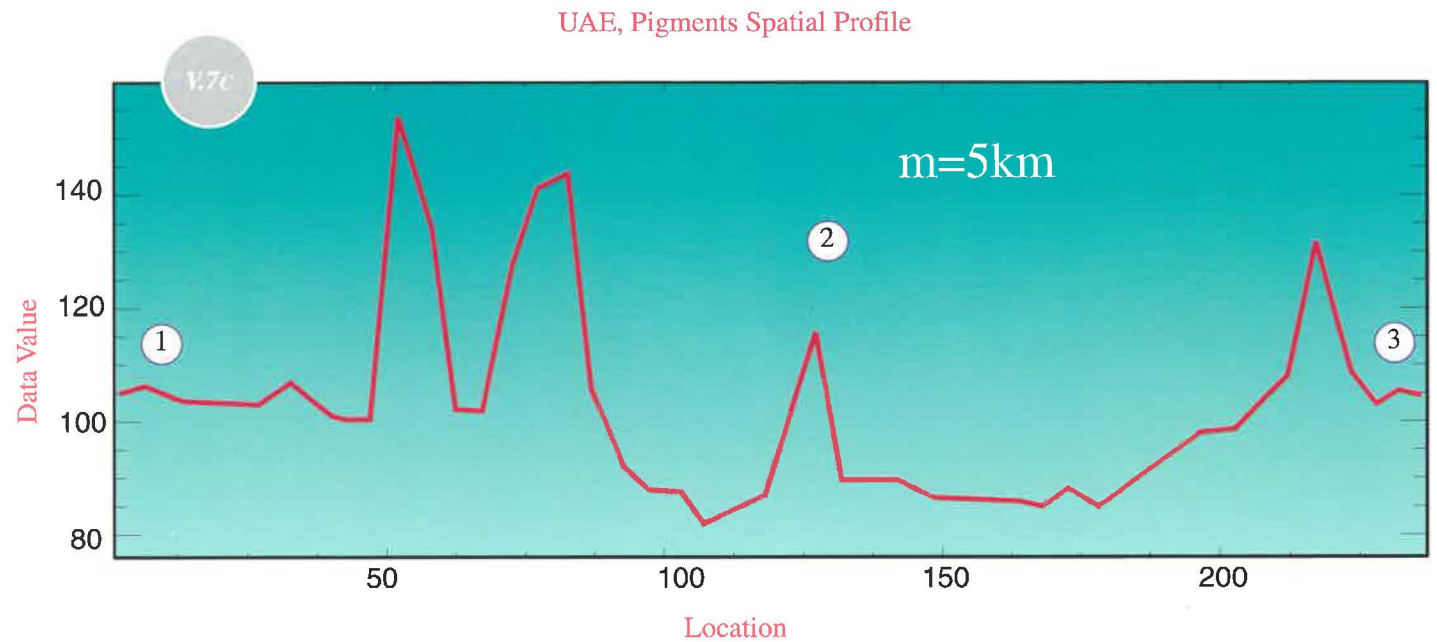


FIGURE V.7D: THE PLOT OF PIGMENTS CONCENTRATION NEAR THE UAE COAST (1995) IS SHOWN ALONG THE TRANSECT FROM FIGURE V.7A

Regularization of the curve of distribution, the average interval is 10 km. Only the larger areas are shown. The concentration of pigment increases with the increase of data value (y axis). The location is shown in relative units between the points.

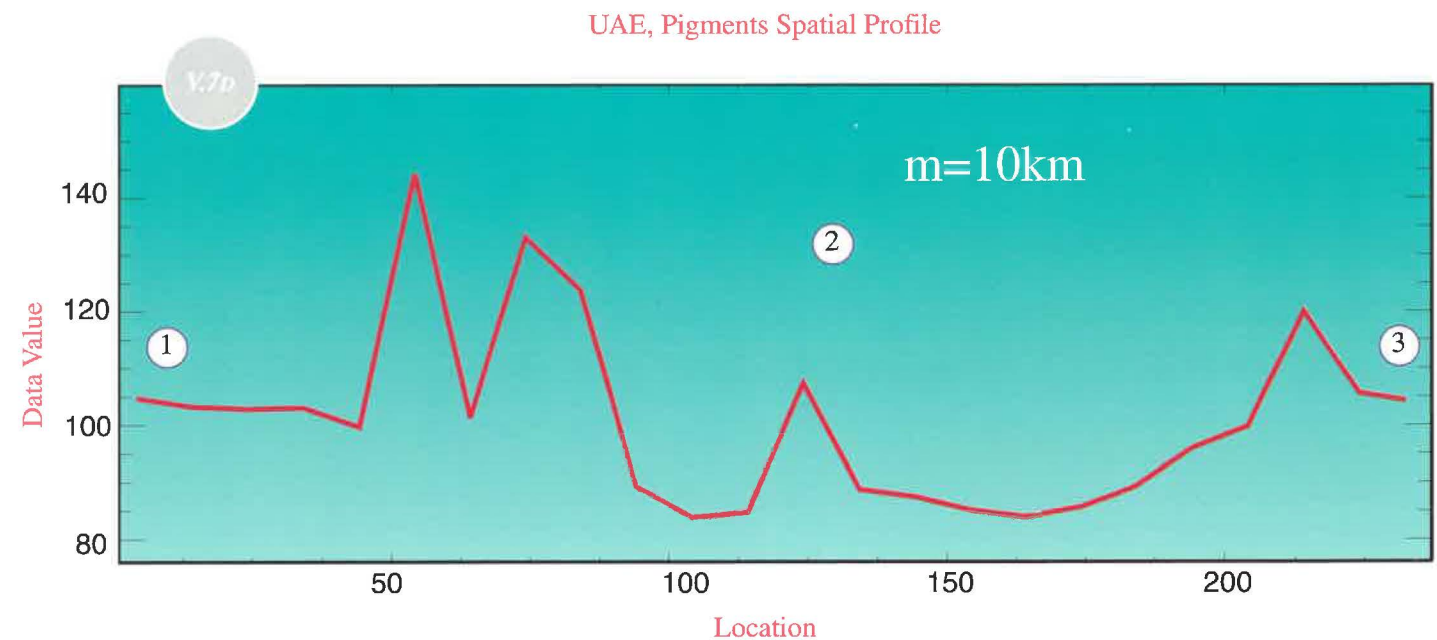




FIGURE V.8A. PIGMENT CONTENTS DISTRIBUTION NEAR THE QESHM ISLAND AND IN THE STRAIT OF HORMUZ.

SCALAR HIGH CONTRAST IMAGE WITH SPATIAL RESOLUTION 1 KM / PXL FROM RSA, THE QESHM ISLAND AND IN THE STRAIT OF HORMUZ, 1995, RETRIEVED FROM NOAA / AVHRR DATA. LIGHT TONES CORRESPOND TO HIGHER PIGMENT CONCENTRATION, DARK TONES - TO LOWER.

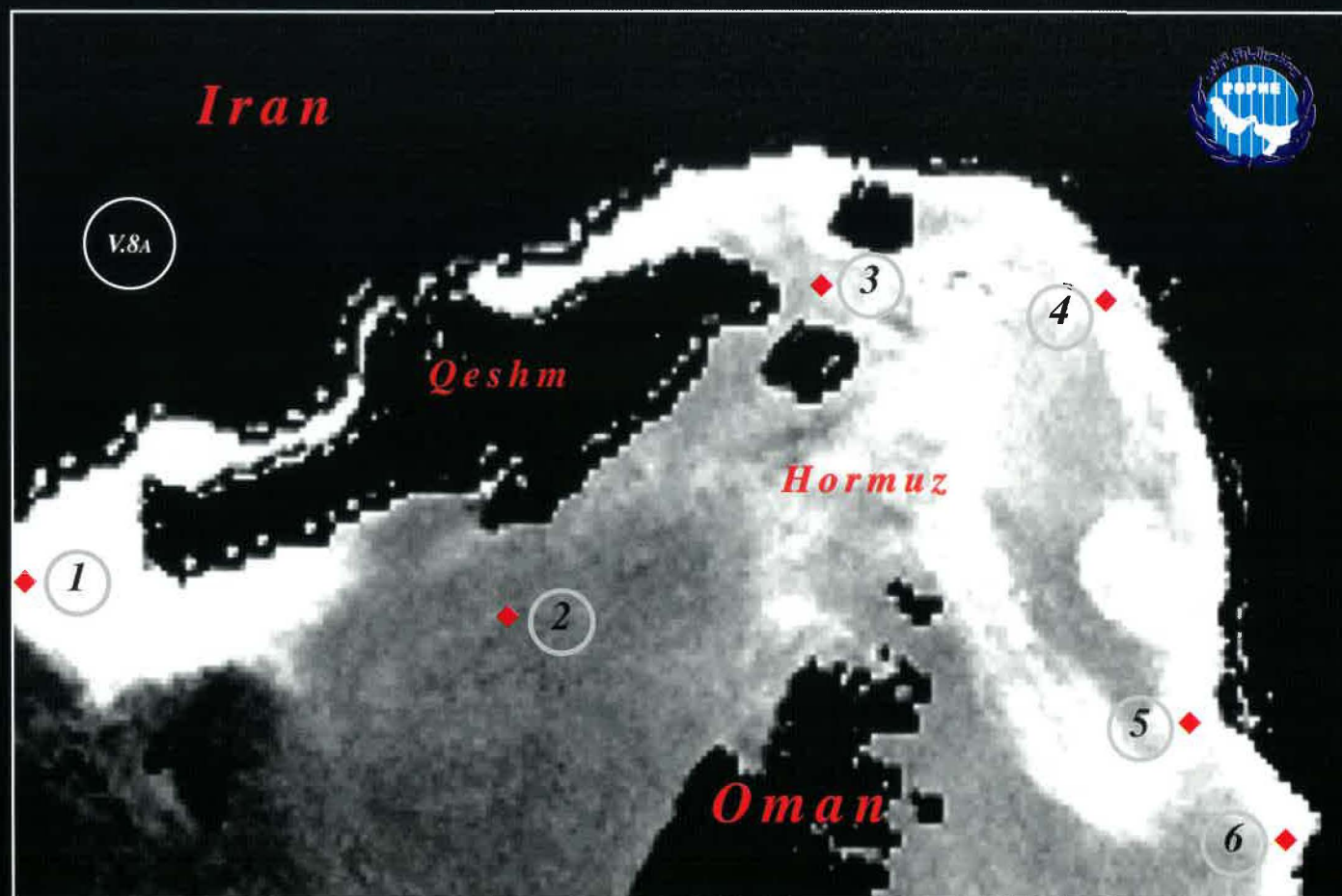
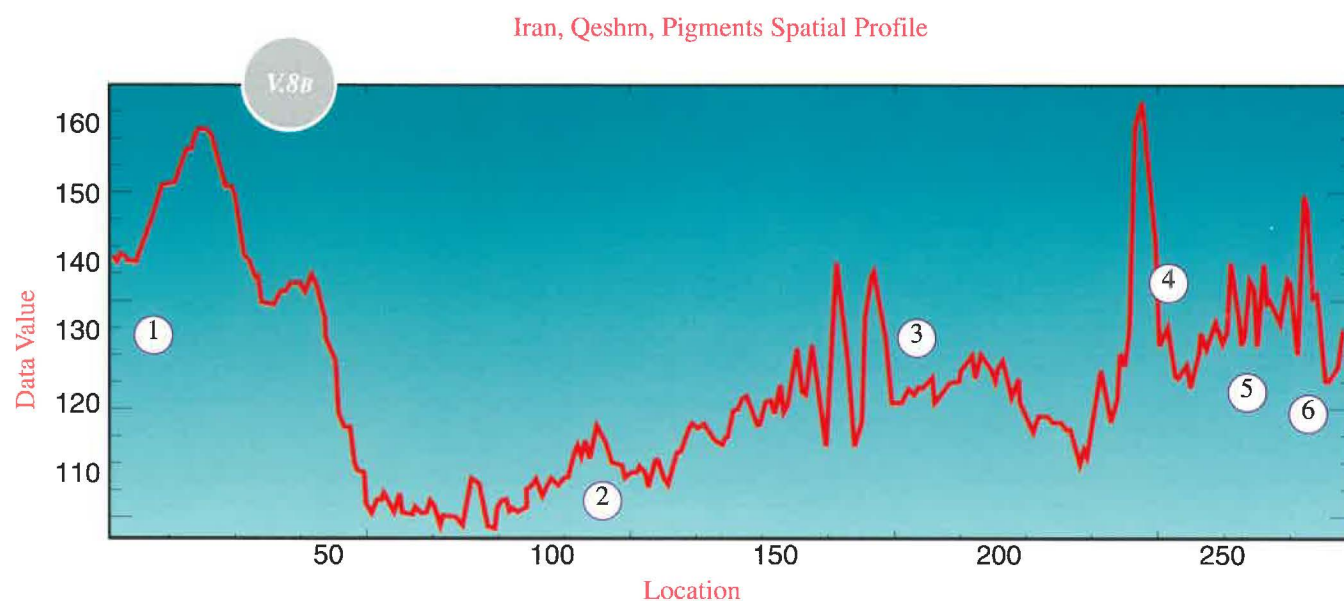


FIGURE V.8B. THE PLOT OF PIGMENTS CONCENTRATION NEAR THE QESHM ISLAND AND IN THE STRAIT OF HORMUZ IS SHOWN, ALONG THE TRANSECT FROM FIGURE V.8A.

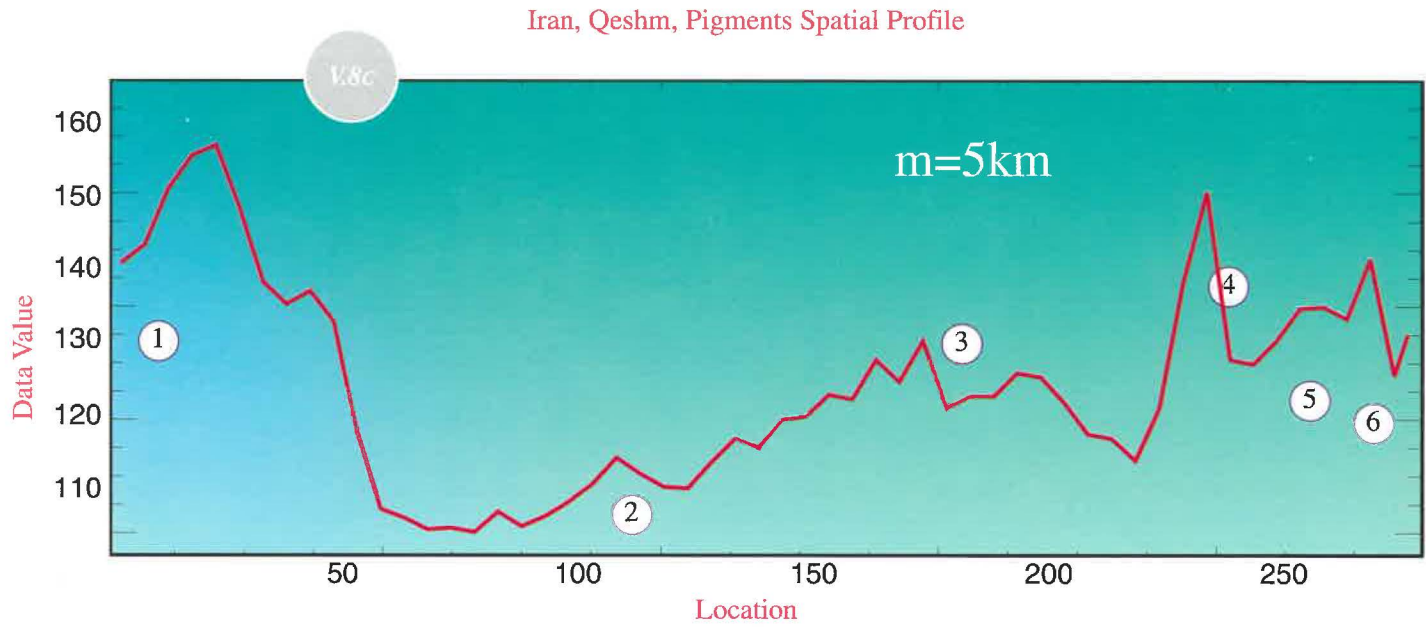
THE CONCENTRATION OF PIGMENT INCREASES WITH THE INCREASE OF DATA VALUE (Y AXIS). THE LOCATION IS SHOWN IN RELATIVE UNITS BETWEEN THE POINTS. SAMPLING INTERVAL IS 1 KM.





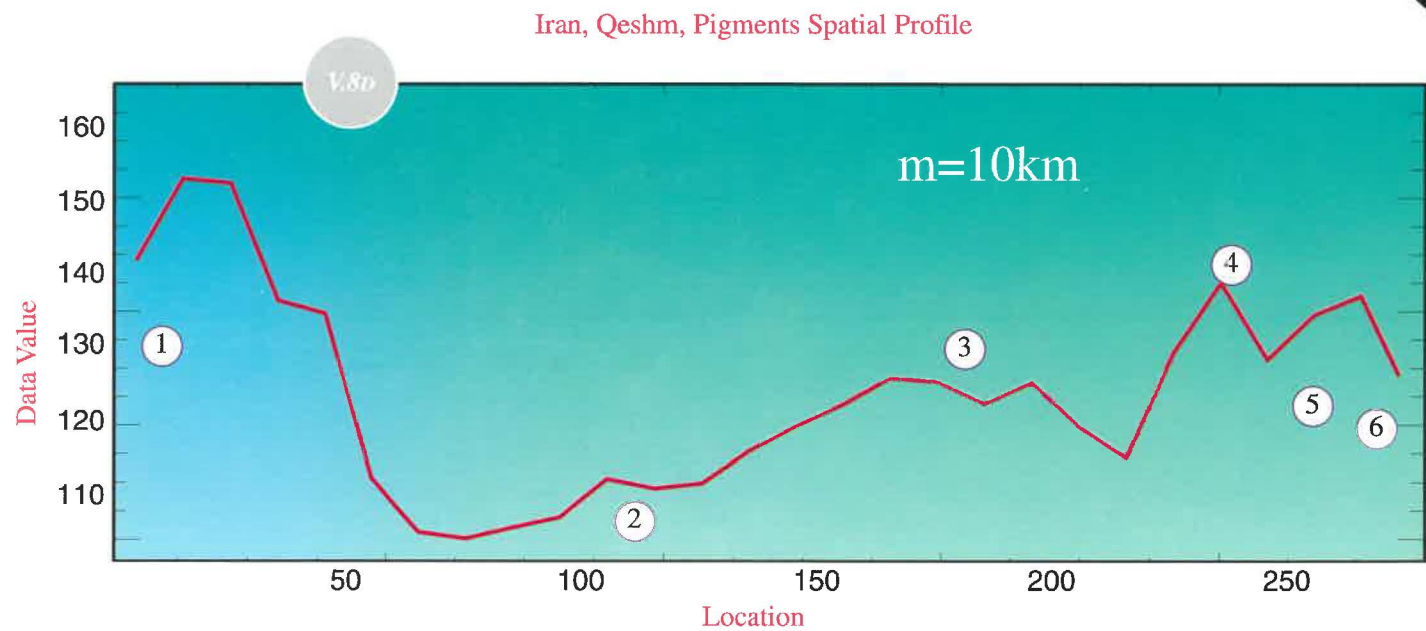
**FIGURE V.8C.** THE PLOT OF THE PIGMENTS CONCENTRATION NEAR THE QESHM ISLAND AND IN THE STRAIT OF HORMUZ IS SHOWN, ALONG THE TRANSECT FROM FIGURE V.8A.

REGULARIZATION OF THE CURVE OF DISTRIBUTION, THE AVERAGE INTERVAL IS 5 KM. THE CONCENTRATION OF PIGMENT INCREASES WITH THE INCREASE OF DATA VALUE (Y AXIS). THE LOCATION IS SHOWN IN RELATIVE UNITS BETWEEN THE POINTS.



**FIGURE V.8D.** THE PLOT OF PIGMENTS CONCENTRATION NEAR THE QESHM ISLAND AND IN THE STRAIT OF HORMUZ IS SHOWN, ALONG THE TRANSECT FROM FIGURE V.8A.

REGULARIZATION OF THE CURVE OF DISTRIBUTION, THE AVERAGE INTERVAL IS 10 KM. IT ONLY SHOWS THE LARGER AREAS. THE CONCENTRATION OF PIGMENT INCREASES WITH THE INCREASE OF DATA VALUE (Y AXIS). THE LOCATION IS SHOWN IN RELATIVE UNITS BETWEEN THE POINTS.



The increase of chlorophyll / pigments contents increases the spectral attenuation coefficient and decreases the penetration of radiance in the visible spectral range in the water. This changes the heating rate on the sea surface, affecting the climate in the region.





*Sand Banks / Coral Reefs*

*Reef Complex  
Fasht Al-Adham*

*Bahrain*

*Mangroves*

*Qatar*

*Saudi Arabia*





# EXAMPLES OF CORAL REEFS HABITATS MAPPING

**C**oral reefs of the world's oceans are the marine analogy of tropical rain forests on land. They are the oldest, most diverse and productive ecosystems in the sea. Reefs are responsible for an estimated 10% of the world's fisheries and serve as the reservoir for much of the ocean's bio-diversity. They may be thought of as the precise bio indicator of the marine environment.

By means of satellite observation systems it is possible to use remote sensing for monitoring coral reefs without having to physically traverse every section of the reef. This approach would make a substantial contribution towards the analysis of changes in coral reef communities.

Satellite systems provide a scale that can be used for mapping of shallow sea floor environments, determining reef from non-reef structures, detecting general distribution patterns (atolls, etc.), providing important information on oceanic processes (surface parameters as SST, colour, etc.) and current patterns around the reefs. Available satellite imagery can be used to delimit multispectral features with spectral resolution in the order of 10 - 30 meters, which is adequate for locating reefs, general distribution patterns, dominant benthic communities (coral, seagrasses, sand, etc.). AVHRR is useful for data on SST and turbidity. This data would be useful in tracking surface warming events, sediment plumes, rivers outputs, and upwellings. On the other hand, SeaWiFS is more useful in the main wavelengths channels for sea bio-optical remote sensing, despite its low spatial resolution. Remote sensing digital image processing techniques used in satellite imagery can be applied easily to aerial and underwater imagery. The compatibility of spectral channels is very important in the above processing. Airborne imaging spectrometry and high-resolution spectrometry (hyperspectral system) would be extremely useful for validation of specific processing techniques concerning reefs monitoring. Utilization of systems like MODIS, AVIRIS, Lewis and MERIS / ENVISAT would provide important data for this activity.

Remote sensing validation studies of some samples of the coral reef community in the RSA will help to improve fundamental knowledge on corals in the Region and the anthropogenic influence on their survival.

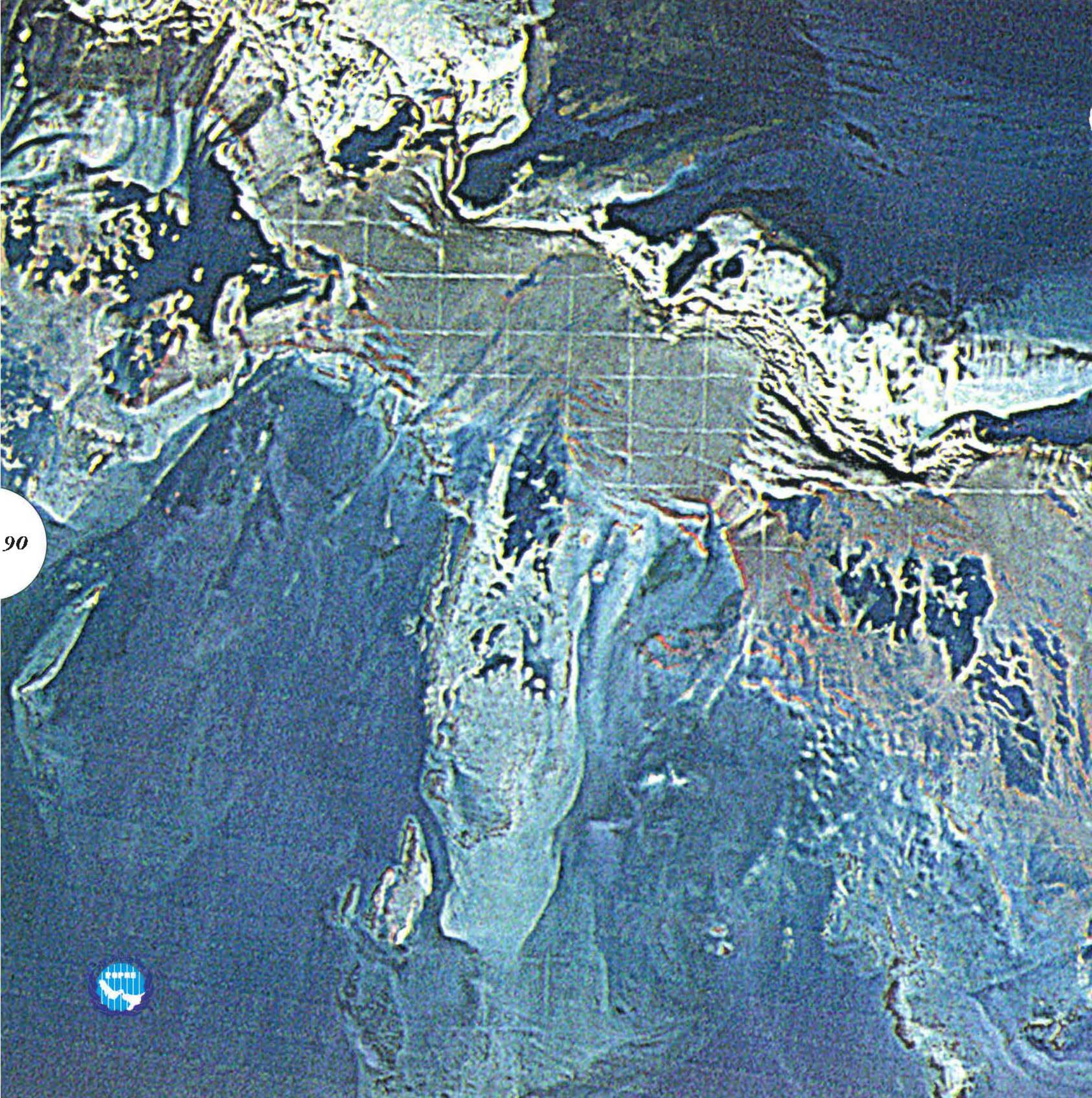


(LEFT) BAHRAIN AND QATAR BATHYMETRY, 7 - 10 METERS DEPTH IS SHOWN IN BLUE. SHALLOW WATERS ARE IN LIGHT BLUE AND MAIN CORAL REEFS, SAND BANKS ARE IN RED. MANGROVES SITUATED NORTH-EAST OF QATAR ARE IN GREENISH COLOURS.

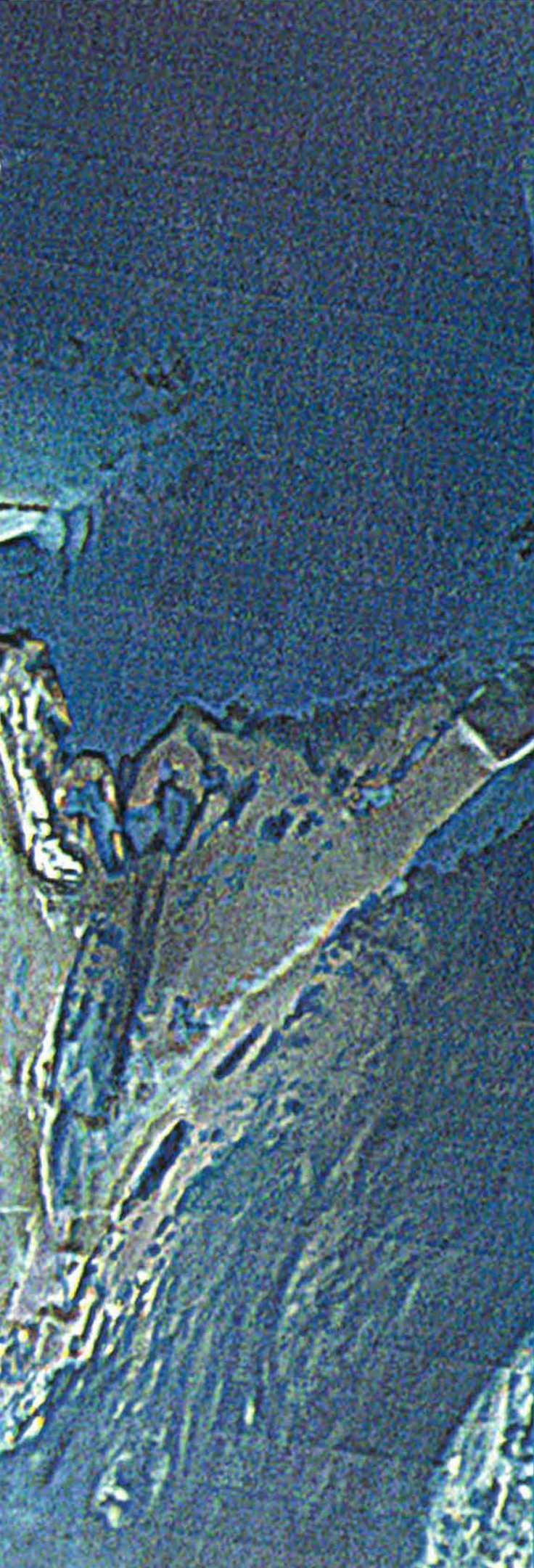
CLOUDS ARE OBSERVED IN NORTHERN QATAR.

LANDSAT 5 THEMATIC MAPPER IMAGE FROM 1995. DIGITAL PROCESSING AND COLOUR COMPOSITION WITH SPATIAL RESOLUTION 30 M/PXL.









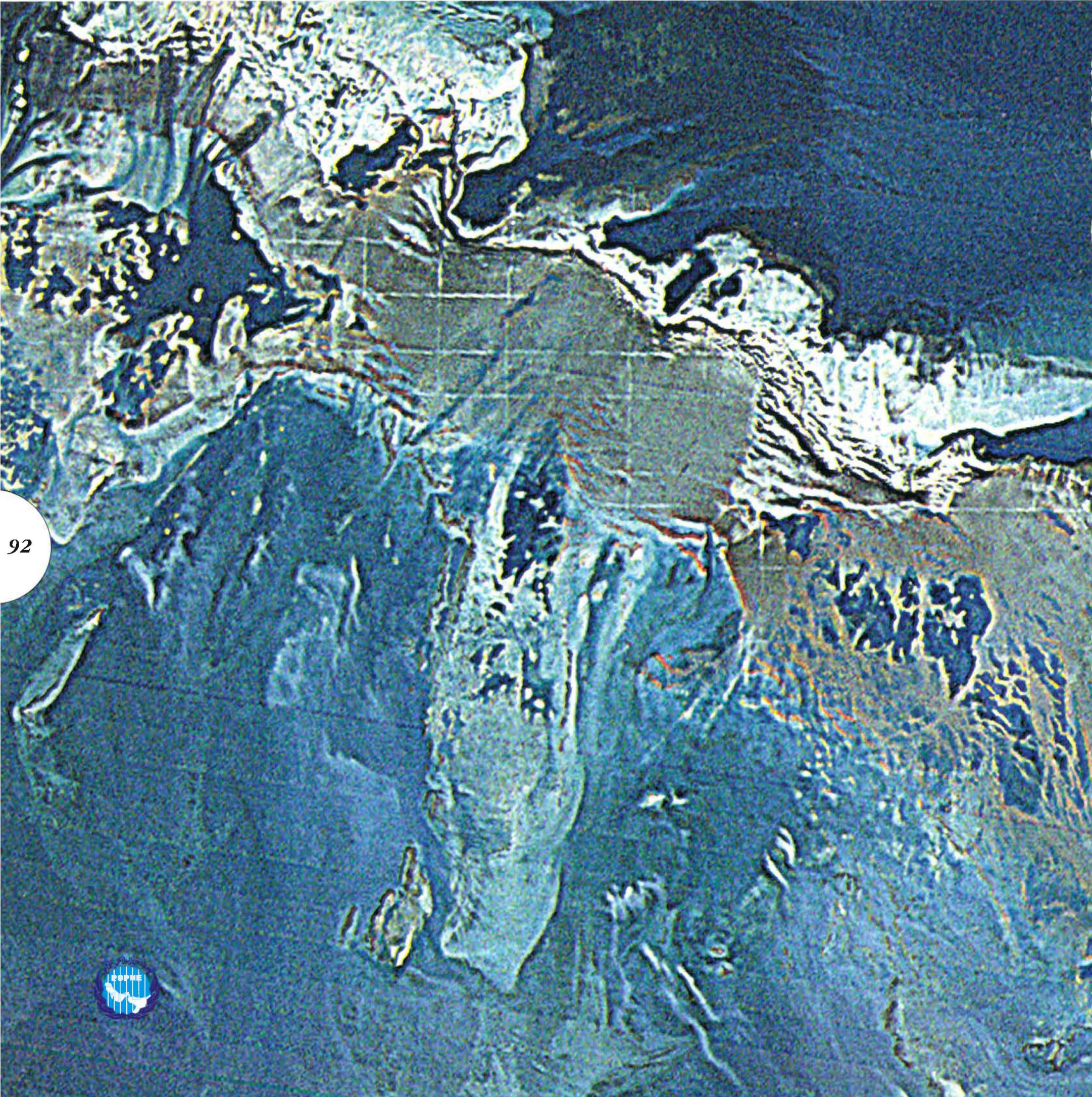
V.10

FIGURE V.10: REEF COMPLEX FASHT AL-ADHAM - ONE OF THE LARGEST AND MOST PRODUCTIVE MARINE ECOSYSTEM IN THE NORTHERN RSA. IT IS POSSIBLE TO SEE TRENCHES FROM SURVEILLANCE.

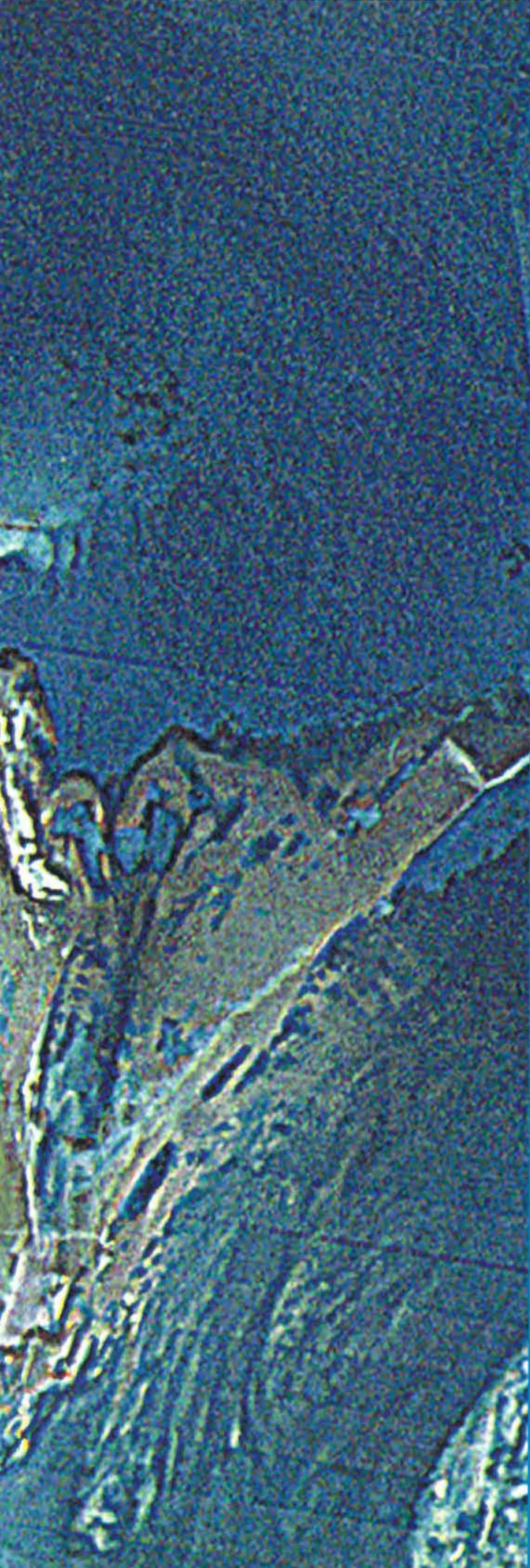
LANDSAT 5 THEMATIC MAPPER, IMAGE FROM 1994. DIGITAL PROCESSING AND COLOUR COMPOSITION WITH SPATIAL RESOLUTION 30 M/PXL.











REEF COMPLEX FASHT AL-ADHAM - A YEAR LATER (1995), SEDIMENTATION COVERS SOME OF THE TRENCHES.

LANDSAT 5 THEMATIC MAPPER, IMAGE FROM 1995. DIGITAL PROCESSING AND COLOUR COMPOSITION WITH SPATIAL RESOLUTION 30 M/PXL.

### *Future Aspects of Satellite Ocean Colour Measurements*

Satellite ocean colour measurements are an essential component of future ocean field experiments. The key role of ocean productivity in global change needs systematic measurements of sea surface colour parameters. NASA and private industries, already released the Sea - Viewing Wide Field Sensor (SeaWiFS). NASA is planning a Moderate Resolution Imaging Spectrometer (MODIS) and a High Resolution Imaging Spectrometer (HIRIS) for the first Polar Orbiting Platform of the Earth Observing System (EOS). In the year 2000, Medium Resolution Imaging Spectrometer (MERIS) instrument is planned to be launched on board ESA / ENVISAT.







CENTRAL PART OF INNER ROPME SEA AREA, EASTERN QATAR AND UAE COAST. URBAN AREAS ARE SEEN IN LIGHT GREY - WHITE WITHIN ARTIFICIAL LINEAMENT STRUCTURES. SABKHA AREAS APPEAR AS LIGHT GREYISH PATCHES ON THE DARK ARID LAND SURFACE. OIL SPILLS ARE EASILY DETECTED BY RADARSAT. THE DARK OIL PATTERNS IN THE WATER REFLECT THE MOVEMENT OF SEA CURRENTS AND WIND. LIGHT SPOTS IN THE SEA REPRESENT SHIPS. THE GREY TONES IN THE WATER REFLECT THE SEA SURFACE AND WIND CONDITIONS.





VI.2A

(LEFT): NOAA14 / AVHRR FRAGMENT  
OF ROPME REGION, MARCH 1997,  
FALSE COLOUR COMPOSITION (RGB  
COLOUR COMPOSITE, CH2, CH1, CH1).

LINEAR LUT VISUALIZATION OF FALSE COLOUR  
IMAGE WAS USED.

There are 2 predominant colours in the  
land cover on the image: deep red and  
grey.

The water body is dark grey and black.  
Shallow waters are in green. Clouds  
appear as white patches in the north  
(South of Iraq, Iran), south-east (Oman  
coast and Gulf of Oman), and south-west  
(Saudi Arabia) corners of the image.  
Snow cover on the Zagros Mountain is  
also white (in the north of the image).  
The grey areas indicate urban areas and  
some barren soil (overgrazing, rough  
grazing / nomadic herding areas, barren  
lands, etc). The barren soil and urban  
areas are not uniquely defined by grey.  
Red corresponds to (high reflectance in  
channel 2) vegetation and barren soil  
(rough grazing / nomadic herding areas  
and some barren lands) mainly in Saudi  
Arabia, UAE and Oman. Sabkha areas are  
darker grey (Sabkha Matti - UAE).  
Seawaters are in dark colour. Shallow  
waters, rivers outfalls and lakes are dark  
grey-green.

Other features include bodies of water,  
snow and clouds, sediments, and shallow  
waters.

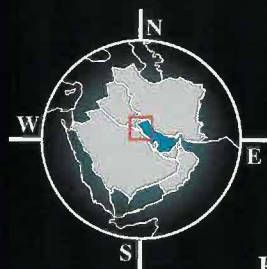
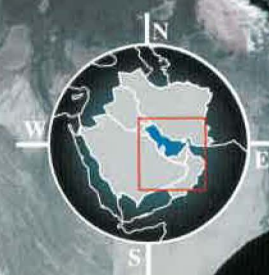


FIGURE VI.2B: A FRAGMENT OF THE  
IMAGE (FIGURE VI.2A) OF THE CENTRAL  
PART OF KUWAIT.

THE URBAN AREAS ARE MOST DISTINCT  
IN CHANNEL 1 OF THE IMAGE (SEE  
KUWAIT CITY, THE DARK GREY TEXTURE IN  
THE SOUTH-EAST OF THE IMAGE). OTHER FEAT-  
URES INCLUDE BODIES OF WATER, CLOUDS, SEDIMENTS, AND  
SHALLOW WATERS. THE WATER BODIES ARE BETTER DEFINED IN  
CHANNEL 2 OF THE IMAGE. THIS CONFIRMS THAT THE INTE-  
GRATED VALUES OF CHANNEL 2 OVER AMBIGUOUS AREAS WERE  
LOWER THAN WOULD BE OBSERVED IF EITHER SURFACE DOMI-  
NATED (BUT ON A VERY LARGE PIXEL SIZE). THIS IS DUE TO A  
MIXTURE OF SCARCE VEGETATION AND BARREN SOIL.



NOAA / AVHRR FRAGMENT OF ROPME REGION,  
RGB COLOUR COMPOSITE, CH2, CH1, CH1, GAUSS LUT





(LEFT): NOAA14 /  
 VI.2c AVHRR FRAGMENT OF  
 ROPME REGION, MARCH  
 1997, FALSE COLOUR (RGB  
 COLOUR COMPOSITE, CH2, CH1,  
 CH1).  
 GAUSS LUT VISUALIZATION.

The light grey area appears to include the arid land areas - vegetation and barren soil - rough grazing / nomadic herding areas and some barren land, mainly in Saudi Arabia, UAE and Oman. The red spots correspond to vegetation cover, such as pastures and scattered farming, woodland in Iran and irrigated farming agriculture areas and oases, on the west coast of the RSA. Sabkha areas are greenish - grey (Sabkha Matti - UAE). Seawaters are dark in colour. Shallow waters, river outfalls and lakes are grey-green.

Clouds appear in shades of white in the north (south of Iraq, Iran), south-east (Oman coast and Gulf of Oman), and south-west (Saudi Arabia) corners of the image. The snow coverage is white (Iran - the Zagros mountain), in the upper part of the image.



FIGURE VI.3: THE NDVI IMAGE OF THE CENTRAL PART OF KUWAIT.

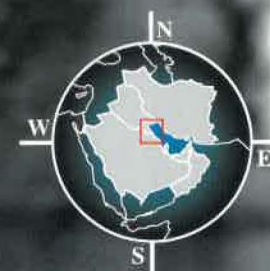
(3) IRRIGATED FARMING - SULAIBIYA,  
 (4) AHMADI, IN THE NORTH - WHITE  
 SPOTS REPRESENT IRRIGATED FARMING  
 - ABDALI. REFERENCE POINTS OUTSIDE  
 KUWAIT; (1), (2), ROUGH GRAZING / NOMADIC  
 HERDING AREAS, (5) IRRIGATED FARMING, SHATT AL-ARAB.



VI.4

THE THERMAL IR BASED, SURFACE TEMPERATURE T<sub>4</sub> (CH<sub>4</sub> IMAGE) OF KUWAIT.

LIGHTER (BRIGHTER) SHADES OF GREY REPRESENT HIGHER RADIANT TEMPERATURE, DARKER = LOWER. SEAWATER IS IN WHITE. LAND SURFACE IS A SHADE OF GREY. DESPITE THE DIFFICULTIES IN DISTINGUISHING BETWEEN URBAN AND NON-URBAN TEXTURES IN HOT DRY BARE ARID SOIL CONDITIONS BECAUSE OF LOW VALUES OF NDVI AND HIGH VALUES OF T<sub>4</sub>, KUWAIT CITY AND SURROUNDING URBAN AREA APPEAR IN SHADES OF GREY, WITH RELATIVELY HIGHER RADIANT TEMPERATURE.





VI.5

THE RELATIONSHIP BETWEEN T4 THERMAL IR BASED, SURFACE TEMPERATURE AND NDVI IS SHOWN (T4 AS FUNCTION ON NDVI). ALONG THE ORDINATE, VALUES OF T4 ARE USED, ALONG THE ABSCISE, VALUES OF NDVI ARE USED.

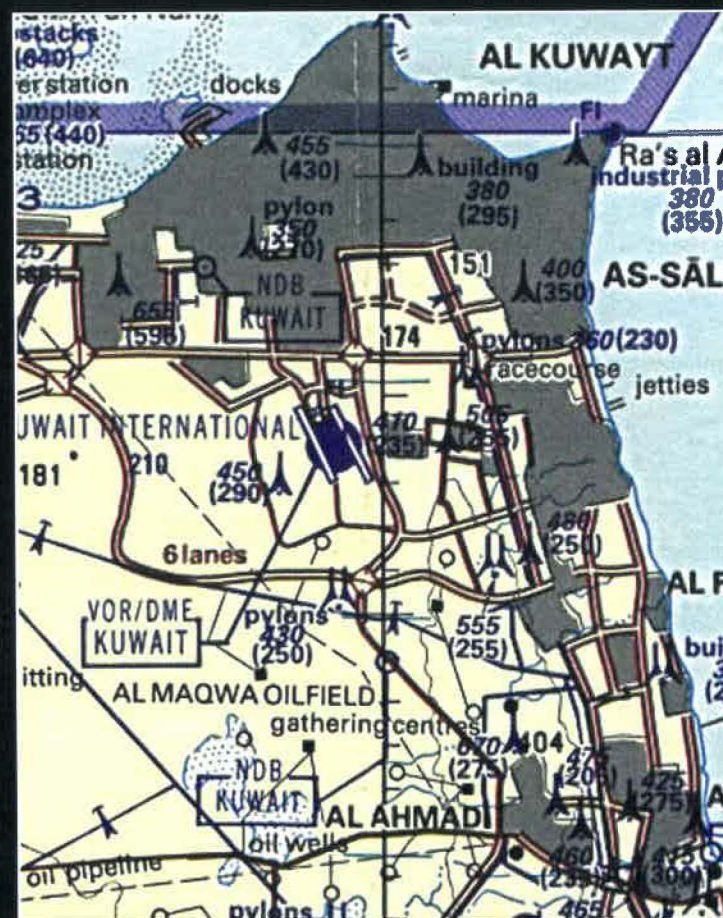
A) BY COMPUTING THE RELATIONSHIP BETWEEN T4 AND NDVI FROM THE PIXELS ASSOCIATED WITH THE VEGETATED AGRICULTURAL AREA (SULAIBIYA), HIGH NDVI VALUES AND RELATIVELY LOW T4 VALUES WERE OBTAINED.

B) BY COMPUTING THE RELATIONSHIP BETWEEN T4 AND NDVI FROM THE PIXELS ASSOCIATED WITH KUWAIT'S URBAN AREAS, HIGHER T4 VALUES WERE OBTAINED.

C) BY COMPUTING THE RELATIONSHIP BETWEEN T4 AND NDVI FROM THE PIXELS ASSOCIATED WITH KUWAIT'S COASTAL ZONE (RAS SALMIYA - RAS AL-ZOOR) IT SHOWS A WIDER VARIATION IN SURFACE TEMPERATURE T4 WHEN COMPARED TO URBAN AREAS (FIG.VI. 5B) OR DENSELY VEGETATED LOCATIONS (FIG.VI. 5A). IT SHOWS MIXED AREAS WITH SPARSE VEGETATION AND LESS DENSITY OF URBANIZATION IN ARID REGION.







## LOCAL HEAT ISLAND - KUWAIT CITY



THE THERMAL IR BASED SURFACE TEMPERATURE T4 (CH4) IMAGE OF KUWAIT CITY AND ITS SURROUNDINGS. LIGHTER (BRIGHTER) SHADES OF GREY REPRESENT HIGHER RADIANT TEMPERATURE, DARKER - LOWER. THE TEMPERATURE OF SEAWATER IS HIGHER, SHOWN AS WHITE. LAND SURFACE IS A SHADE OF GREY. DESPITE THE DIFFICULTIES

IN DISTINGUISHING BETWEEN URBAN AND NON URBAN TEXTURES IN HOT DRY BARE ARID SOIL CONDITIONS, HIGH VALUES OF T4 KUWAIT CITY URBAN AREA APPEAR IN SHADES OF GREY WITH RELATIVELY HIGHER RADIANT TEMPERATURE. HIGH CORRELATION BETWEEN LIGHT SPOTS IN THE IMAGE AND URBAN AREAS ON THE MAP IS OBSERVED.



# OIL SPILLS IN THE ROPME REGION

**A**ssessment of Oil Spills in the ROPME Sea Area. Oil pollution in the ROPME Sea Area (RSA) has increased in the last twenty years and is one of the major ecological problems and dangers for the marine ecosystems in the region.

Over the past decades, remote sensing has demonstrated the effectiveness of space-based platforms in monitoring the marine environment. Some results of remote sensing monitoring of oil slicks in the RSA are presented.

Widespread man-made pollution of the sea that can be detected by current space borne systems is concentrated particularly in the RSA. The amount of petroleum products ending up in the ocean is estimated at more than 6 million tons of the world's oil production. Transportation of large quantities of crude oil through the Region is another serious problem. More than 10,000 seagoing tankers cross RSA each year. In general, oil spilling from platforms and ships in the area is usually reported quickly through standard routine checks. However, illegal oil spills and accidents, which are not reported, are currently causing problems. Locally, especially in coastal regions, a sudden spill of oil into the sea can have catastrophic consequences that are usually short-lived. The oil spills may endanger and destroy the fragile intertidal zones, mangrove forests and wildlife habitats. The contaminated shallow coastal areas normally provide feeding grounds for birds, as well as feeding and nursery areas for fish and shrimp. Since the plants and animals of the seafloor are the basis of the food chain, damage to the shoreline has consequences for the whole shallow-water ecosystem, including the multimillion-dollar member states fisheries industry.

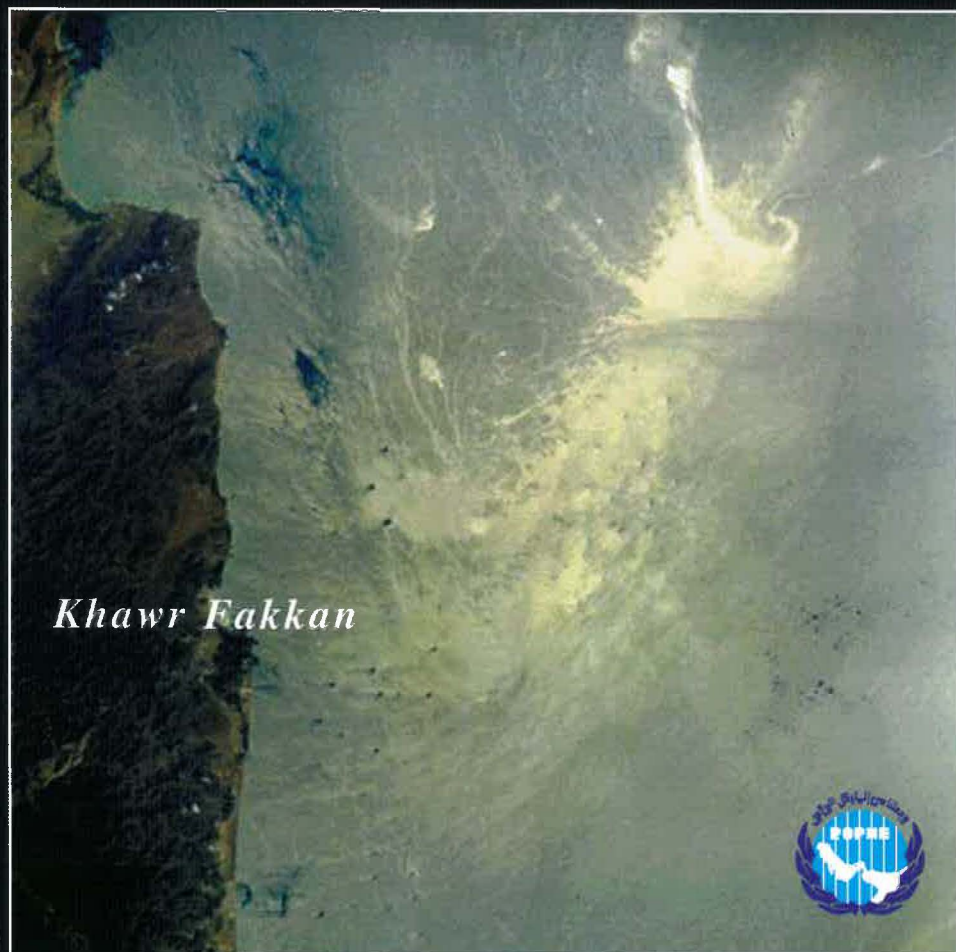
Regular information on marine constituents and their relationship with physical and anthropogenic factors can be obtained from integrated satellite observations from manned space flights and automatic orbital platforms. Data from NOAA, ERS, Landsat TM, CZCS archive, and new advanced satellite observation programmes, such as SeaWiFS, MODIS, ENVISAT are the basis of sea surface pollution monitoring. Visible satellite images are important for coastal studies since their penetration of the water surface allows water quality evaluation (depth, turbidity, suspended sediments concentration, chlorophyll, etc.). Observation in thermal IR and microwave spectral range are mostly used for SST, wind speed, oil plumes, off-shore circulation, etc. Long term exploitation of AVHRR on board NOAA satellites, Landsat, SPOT, Radarsat, SeaWiFS and operational applications of CZCS archive for primary production makes these instruments most applicable for monitoring seasonal and spatial variability of some marine contaminants.

The utilization of the above orbital platforms during the last crisis in the RSA for the estimation of environmental disasters on a daily basis (oil release, fire plumes, etc.) showed unprecedented ability when compared to other monitoring systems.

MAJOR OIL SPILLS IN ROPME SA

| Date       |                             | Millions of Barrels |
|------------|-----------------------------|---------------------|
| 05/25/1978 | WELL 126, I.R. IRAN         | 0.7                 |
| 08/20/1981 | KUWAIT PETROLEUM TANKERS    | 0.7                 |
| 02/04/1983 | NOWRUZ, I.R. IRAN           | 1.9                 |
| 10/1983    | QATAR                       | 0.3                 |
| 08/15/1985 | KHAR ISLAND, I.R. IRAN      | 0.5                 |
| 21/01/1991 | GULF WAR OIL SPILLS, KUWAIT | 6 - 8               |





VI.7

(ABOVE) NORTHERN COAST OF OMAN.  
MASSIVE PETROLEUM SLICKS IN ANCHOR-  
AGE AREAS OF SUPER TANKERS OFF THE  
NORTHERN COAST OF OMAN, 1983.

LIGHTER SPOTS REPRESENT OIL SLICKS. SPACE  
SHUTTLE OBSERVATIONS, (NASA, GSFC ARCHIVE).



VI.8A

(BELOW) OIL POLLUTION NEAR THE ISLAND  
OF SIR ABU NU'AYR, RSA, 1984

LIGHTER SPOTS NEAR FATEH OIL FIELD REPRESENT  
OIL SLICKS. SPACE SHUTTLE OBSERVATIONS, (NASA,  
GSFC ARCHIVE).

VI.8B

(FACING PAGE) OIL SLICK LOCATION ON  
THE COINCIDENT CZCS SCENE OF THE RSA.

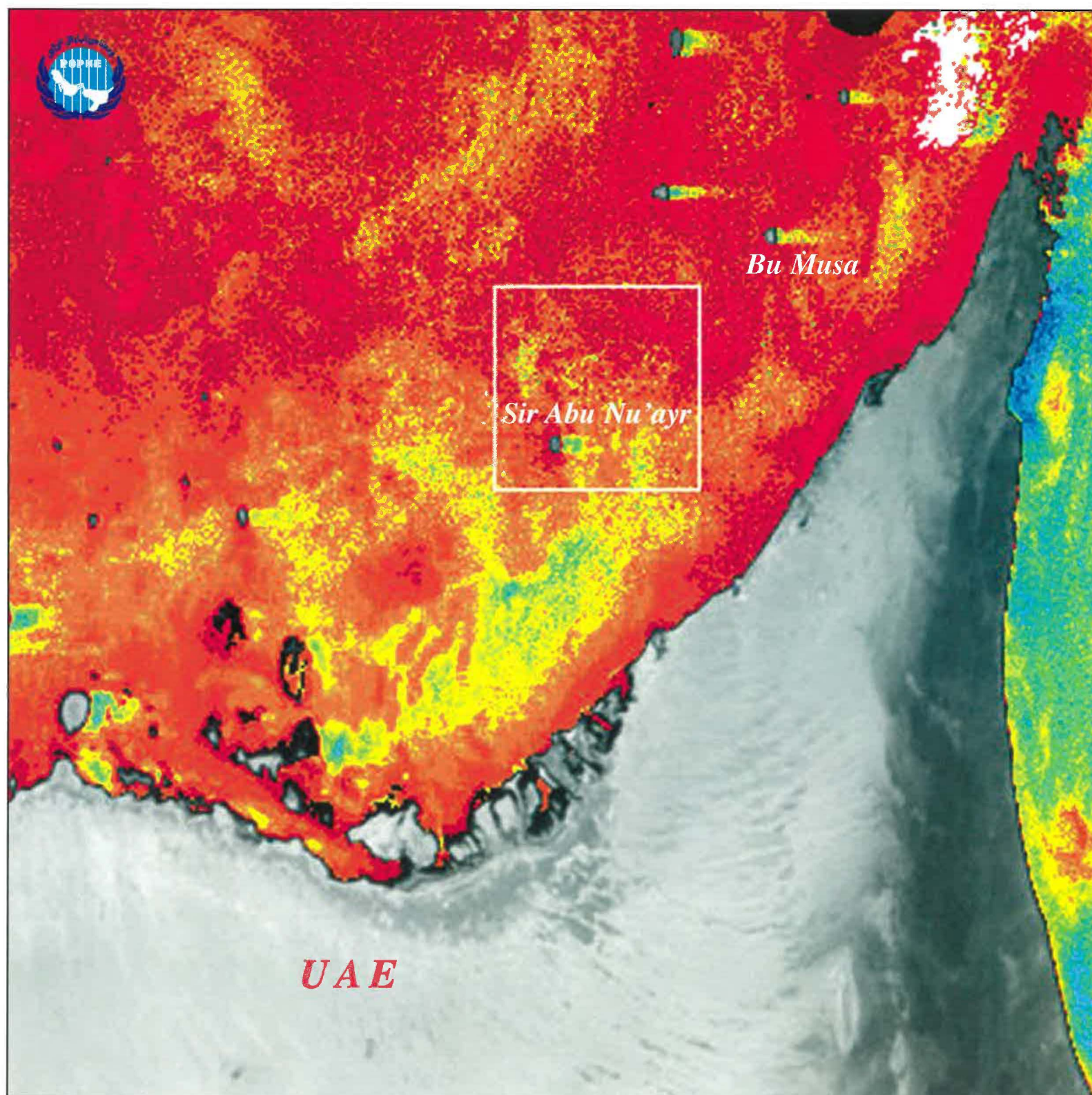
THE WHITE BOX IN THE CZCS IMAGE FROM NIMBUS  
7 SHOWS THE LOCATION OF THE PREVIOUS FIG.8A.



*Fateh Oil Field*

*Jazirat Sir Abu Nu'ayr*







*Mina al Malik*

*Saudi Arabia*

*Bahrain*



VI.9

(LEFT) MASSIVE OIL SLICKS NEAR BAHRAIN, 1985. THE LARGE AREA WITH LIGHT COLOURS REPRESENTS OIL SLICKS. SPACE SHUTTLE OBSERVATIONS, (NASA, GSFC ARCHIVE).



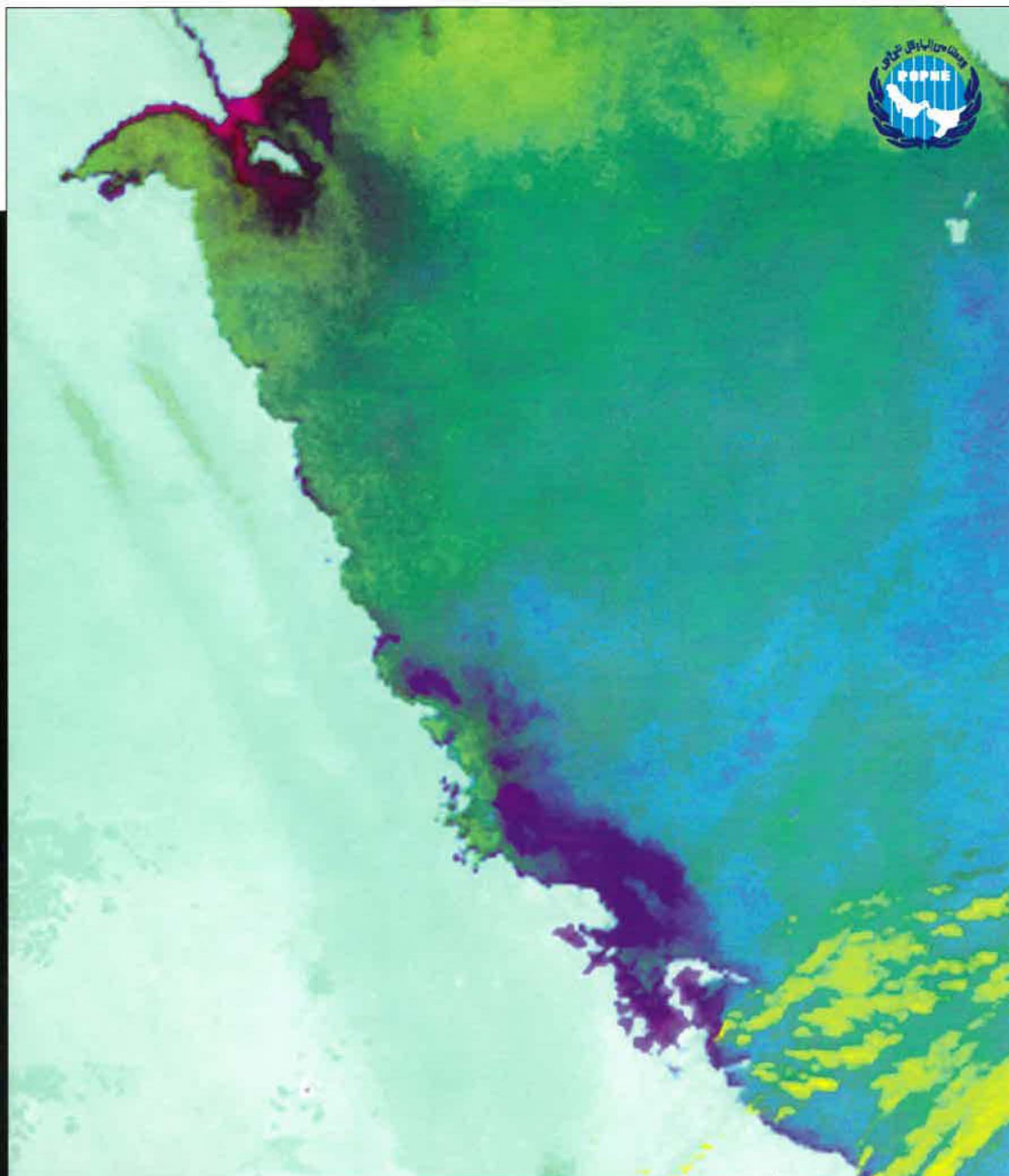
VI.10A

(RIGHT) MASSIVE OIL SPILL IN 1991. THE OIL STORAGE FACILITIES, TERMINALS WERE DESTROYED, AND SEVERAL LOADED TANKERS WERE EMPTIED INTO THE NORTHERN RSA. SPILLED OIL DRIFTED ABOUT 100 KM TO THE SOUTH FROM KUWAIT'S TERMINALS. OIL APPEARS AS PURPLE STREAKS.

A NOAA / AVHRR IMAGE WITH RESOLUTION 1 KM/PXL, JANUARY 1991.







VL10b

ABOVE: MASSIVE OIL SPILL TRAPPED BY THE ABU ALI ISLANDS A FEW WEEKS LATER, SAUDI ARABIA, FEBRUARY 1991. OIL APPEARS AS PURPLE STREAKS

A NOAA / AVHRR IMAGE WITH RESOLUTION 1 KM/PXL, FEBRUARY 1991.







VL10c

(LEFT) SMALL OIL SLICKS NEAR MINA AL - ZOUR, KUWAIT, MAY 1991. OIL APPEARS IN STRIPS OF LIGHT GREENISH-YELLOW.

AERIAL SURVEY, "UNEP GULF IMAGERY" DATA BASE, TEXTURE ANALYSES.

VL10d

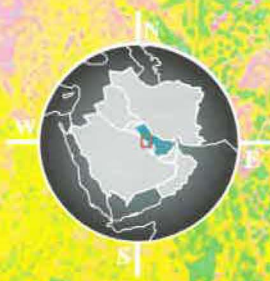
(RIGHT) SEPARATION OF SURFACE OIL SLICKS FROM SHALLOW SAND BOTTOM, OIL SLICKS ARE IN ORANGE, SAND BOTTOM - IN RED. WEST COAST OF RSA, SAUDI ARABIA, MAY 1991.

AERIAL SURVEY, "UNEP GULF IMAGERY" DATA BASE, TEXTURE ANALYSES.

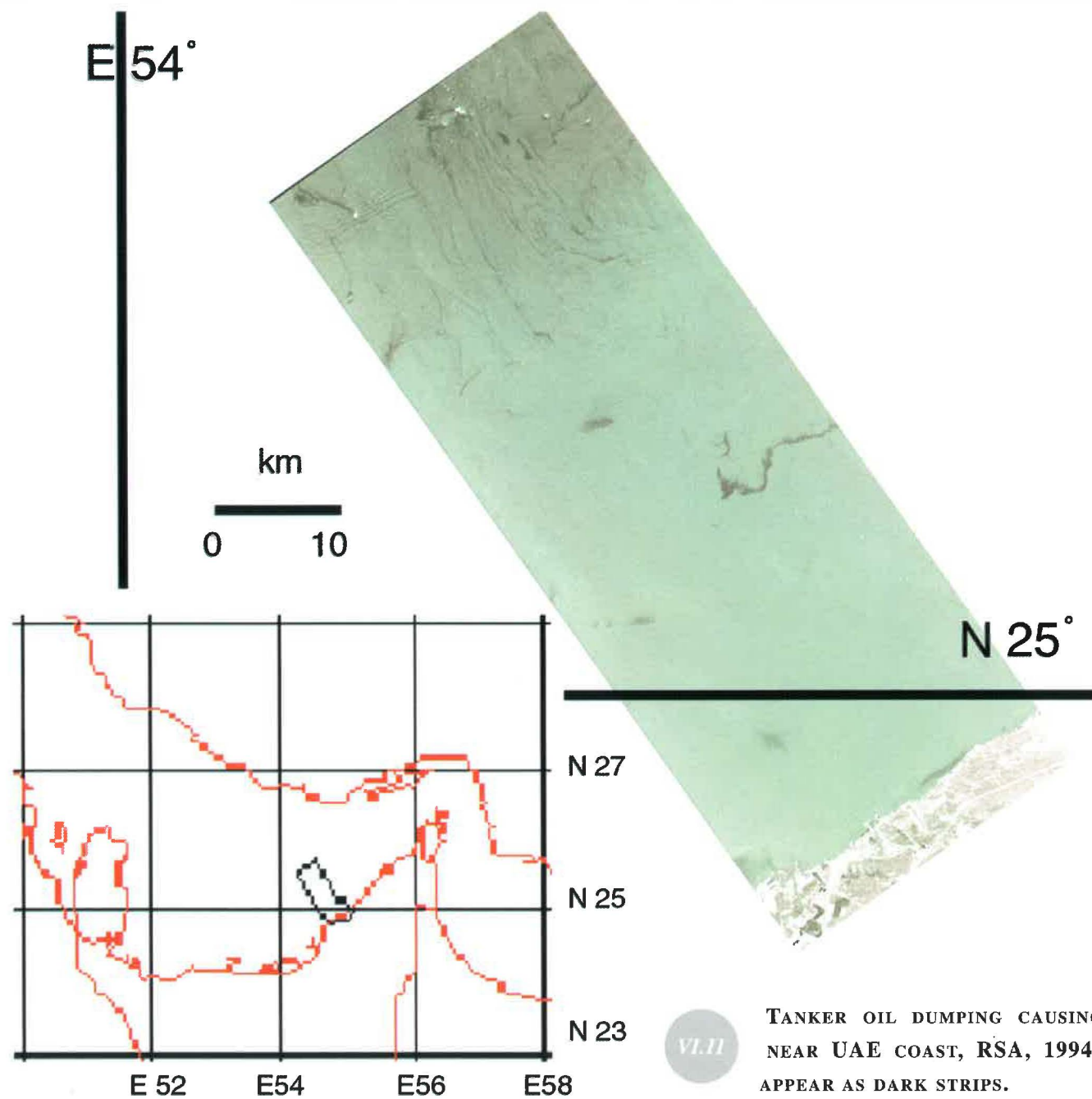
108











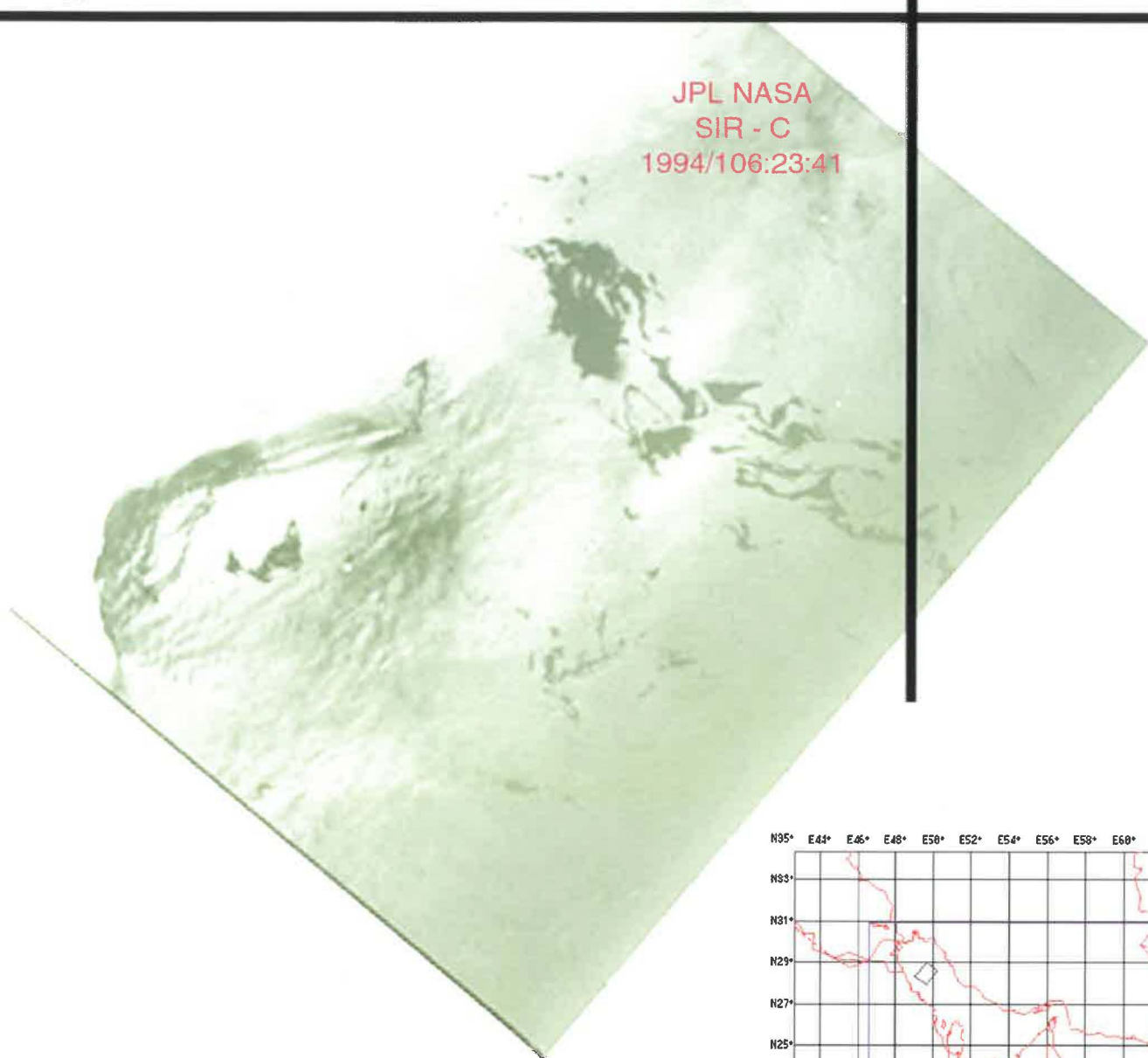
Synthetic Aperture Radar SIR - C, Space Shuttle  
programmes, (NASA, JPL).  
Colour combination of L and C bands.



N 29°

E 50°

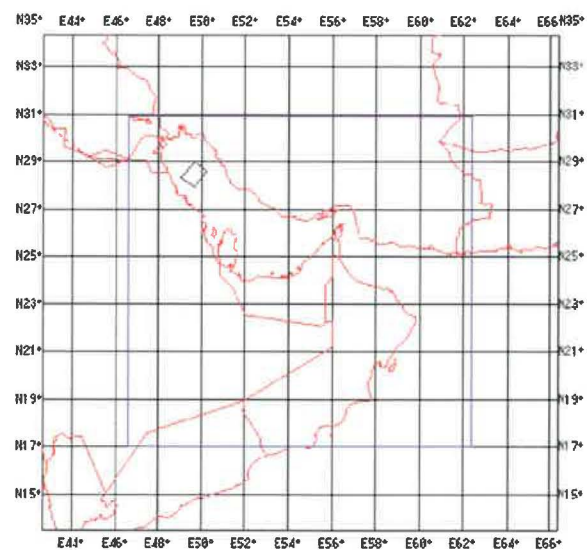
JPL NASA  
SIR - C  
1994/106:23:41



VI.12A

**OIL POLLUTION IN THE NORTHERN PART OF  
RSA, 1994. OIL APPEARS AS DARK STRIPS.**

Synthetic Aperture Radar SIR - C, C band, Space  
Shuttle programmes, (NASA, JPL).





VI.12B

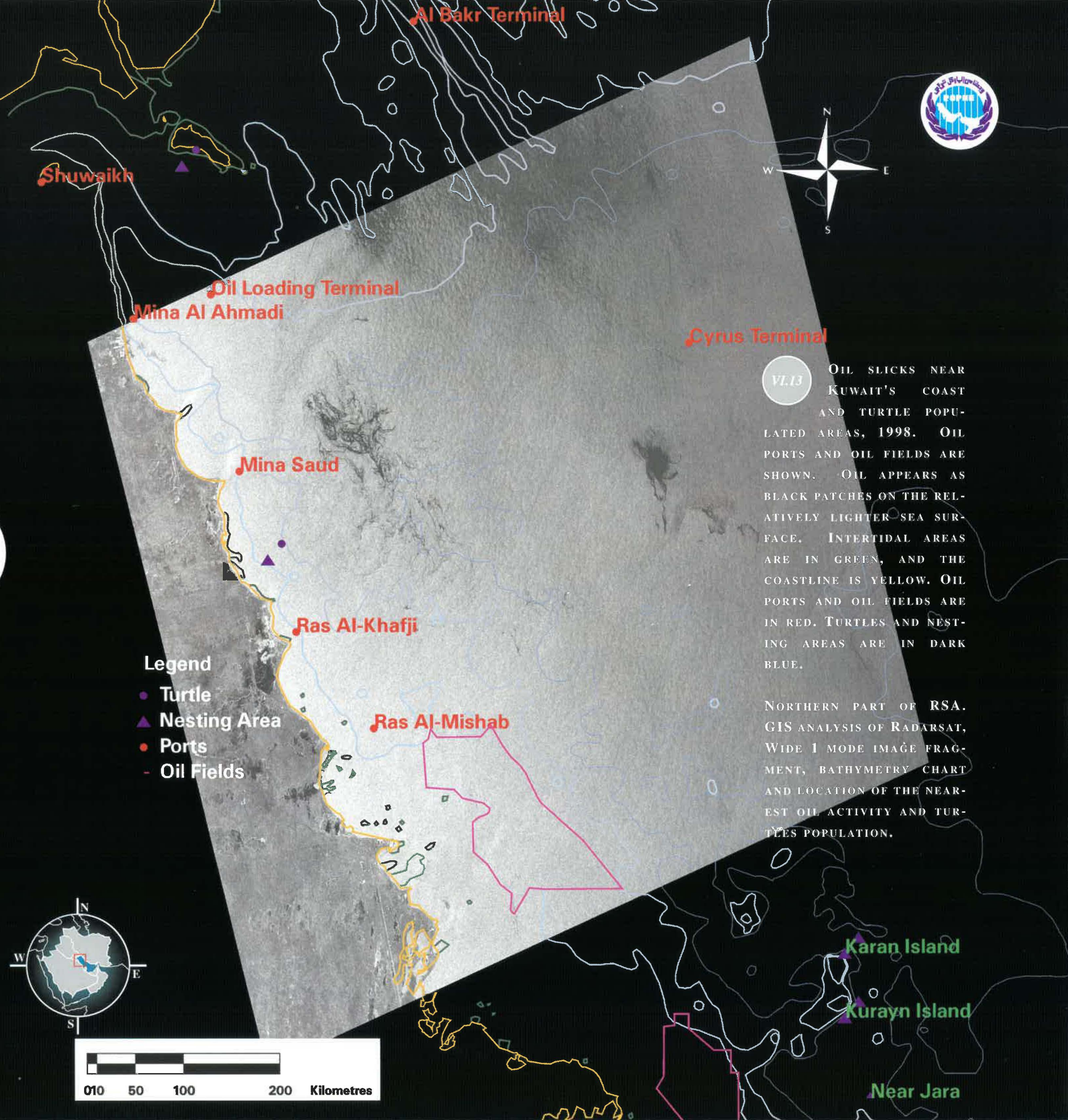
OIL POLLUTION IN THE NORTHERN PART OF RSA, NEAR THE KUWAITI COAST, 1998. OIL APPEARS AS BLACK STRIPS. RADARSAT SYNTHETIC APERTURE RADAR, SAR WIDE 1 MODE, C BAND.















CENTRAL PART OF INNER ROPME SEA AREA (UAE COAST). URBAN AREAS ARE SEEN IN LIGHT BLUE - WHITE WITHIN ARTIFICIAL LINEAMENT STRUCTURES. SABKHA AREAS APPEAR AS LIGHT BLuish PATCHES ON THE DARK ARID LAND SURFACE.

OIL SPILLS ARE EASILY DETECTED BY RADARSAT. THE DARK OIL PATTERNS IN THE WATER REFLECT THE MOVEMENT OF SEA CURRENTS AND WIND. LIGHT SPOTS IN THE SEA REPRESENT SHIPS.

THE BLUE TONES IN THE WATER REFLECT THE SEA SURFACE AND WIND CONDITIONS.









# ASSESSMENT OF ATMOSPHERE IN THE ROPME SEA AREA

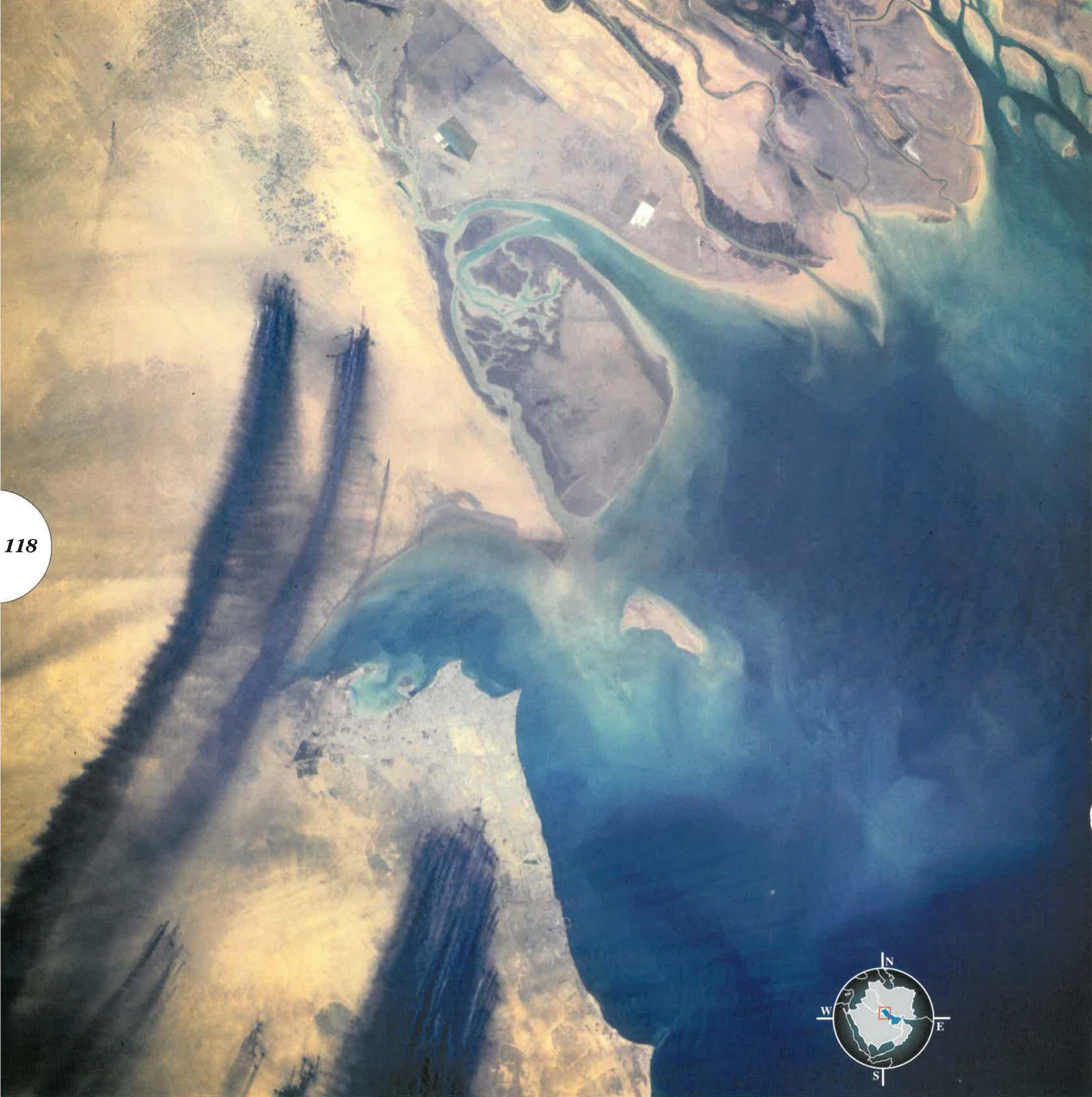


(LEFT) FIRE PLUMES FROM THE OIL WELLS OF THE STATE OF KUWAIT DURING THE 1991 CRISIS. DARK-BLACK TONES REPRESENT THE OIL FIRE PLUMES. THE CONTENT IS MAINLY SOOT, OIL DROPS AND VARIOUS HYDROCARBONS. A LARGE AREA BETWEEN KUWAIT AND SAUDI ARABIA IS ALREADY CONTAMINATED BY SOOT AND OIL DROPS DEPOSIT. ATMOSPHERIC INFLUENCE TRANSFERS THE FIRE PLUMES ALONG THE WEST COAST OF RSA UP TO SULTANATE OF OMAN. BLACK SMOKE IS 5 KM INTO THE SKY.



NOAA / AVHRR IMAGE WITH RESOLUTION 1 KM/PXL FROM, 1991, ROPME/PAAC ARCHIVE. COLOUR COMPOSITION OF VISIBLE AND INFRARED BANDS: CH1, CH2 AND CH3. FILTERING AND EQUALIZATION. RELATIVELY CLEAR ATMOSPHERIC CONDITIONS IN THE RSA.







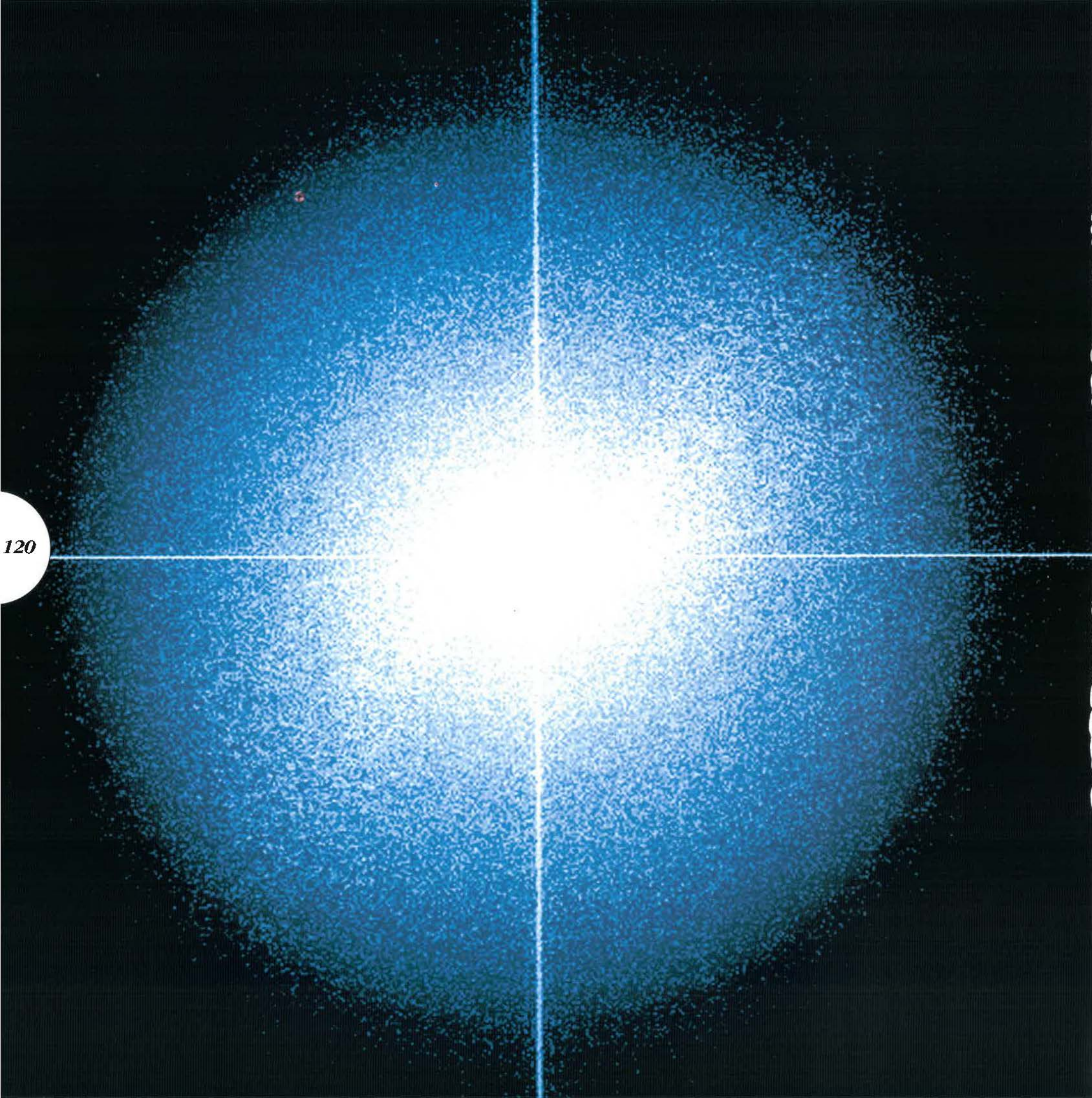
# ASSESSMENT OF ATMOSPHERE IN THE ROPME SEA AREA

VI.14b

(LEFT PAGE) DETAILED VIEW OF SOURCES  
OF FIRE PLUMES FROM THE OIL WELLS IN  
RAWDATAIN, SABRIYAH AND BURGAN OIL  
FIELDS. SPRING 1991.

DIGITAL IMAGE PROCESSING, STATISTICAL  
FILTERING. HIGH RESOLUTION DATA. TRUE  
COLOURS IMAGE. SPRING 1991. SPACE SHUTTLE  
OBSERVATIONS (LARGE CAMERA), (NASA, GSFC  
ARCHIVE).







## VII. STRUCTURAL ANALYSES OF PHENOMENA IN THE REGION

The interest in the extensive research of the structure of the phenomena on the Earth's surface has been demonstrated by the creation of multispectral scanners in the 1960s and 1970s with an increasing number of channels. Nowadays, this can be done by means of a hyperspectral approach - imaging spectrometry applications. The selected spectral descriptions of the Earth's surface have caused the occurrence of new methods of complex processing of video information, non-conventional in practice with previous remote sensing methods. Also, more extensive research of the textural characteristics of the signatures has been carried out, which are associated with the parameters of the integral transformations (Fourier, Hadamard spectrum). The Fast Fourier Transform (FFT) is applied in geology for separating geological features, in atmosphere and cloud analyses, in climatology and environmental studies to identify time dependent phenomena.

To separate more informative features, in addition to the spectral signature method, the structural symptoms characterizing the type of object are studied. To identify these symptoms, an integral transformation was involved. For instance, Fourier, Hadamard give the general properties of the image from the scene through the interconnection of the different elements.

The analysis of the two dimensional spectrum  $F_{\lambda}(W_x, W_y)$  for each channel  $\lambda$  is especially suitable for obtaining the spectral structural characteristics.

$$\{F_{\lambda}(W_x, W_y)\} = \{\sum \sum H_{\lambda}(x, y) \exp (2\pi j(W_{xx} + W_{yy})) \Delta x \Delta y\}$$

The grouping of the spatial frequencies for each spectral channel enables the analysis of the spatial structure of the natural formation in different channels - separating the phenomena into a set of filters. The particular advantage of the two dimensional spectra is their ability to analyze in real time, which allows the creation of a large library of structural characteristics.

The main objective in the case of structural analysis is the separation of the elementary textures: structural "fingerprints" of the type of natural formations through the analysis of grouping of harmonics in the frequency domain (multitude of channels spectra). The examination of the content in the short-wave channels enables the assessment of the atmosphere filter and its conditions (existing pollutants).

In the same manner, the anisotropy of the FFT spectrum could indicate the level of anthropogenic influence such as: industrial, urban, and agricultural activity; natural features such as geological structures, etc.

The FFT spectrum frequency is an indicator of the spatial resolution of the image. Images with high spectrum frequency are with higher spatial resolution. The impact of the atmosphere on the reflected radiation from the Earth in the visible spectral range could be described as a low frequency filter.



# STRUCTURAL ANALYSES OF INDUSTRIAL FACILITIES



## *Plant*

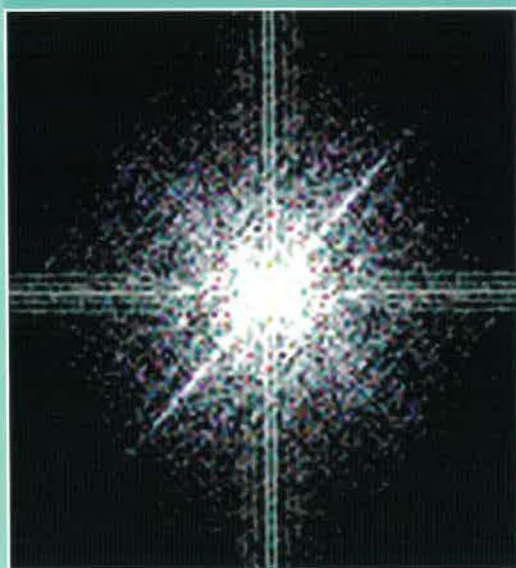
POWER PLANT,  
MINA AL-ZOUR, KUWAIT

### *Upper*

RELATIVELY CLEAR ATMOSPHERE. IMAGE FRAGMENT  
FROM AERIAL COLOUR INFRARED PHOTOGRAPH. RGB  
COLOUR COMPOSITION IS ANALYSED. ROPME RS  
ARCHIVE.

### *Lower*

FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAG-  
MENT IS SHOWN. RGB COLOUR COMPOSITION OF  
FOURIER MAGNITUDE OF THE 3 CHANNELS OF ABOVE  
FRAGMENT IS SHOWN.



The high frequency groups are in the orthogonal  
direction to the main lineaments in the above frag-  
ment. The figure represents a typical "fingerprint" for  
artificial surface structures - sharp frequencies group  
and periodical geometry in the frequency domain. The  
main power of the spectrum (white colour of main  
frequency groups) shows similar behavior in all chan-  
nels.





## Road

TAR HIGHWAY IN THE DESERT  
AL - ZOUR AREA, KUWAIT

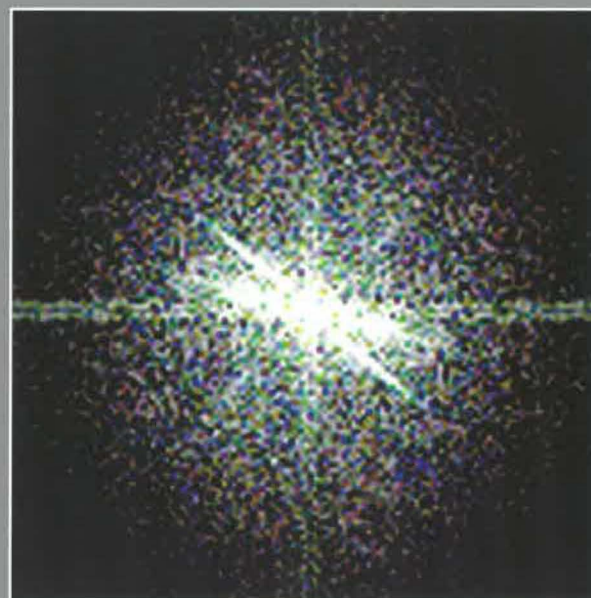
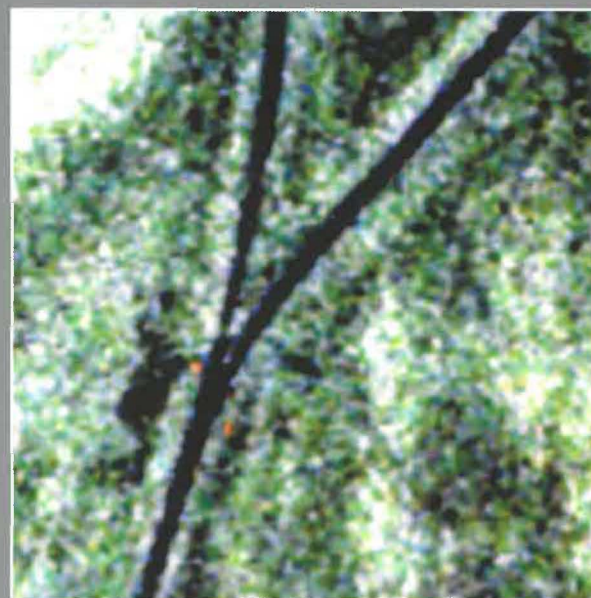
### Upper

RELATIVELY CLEAR ATMOSPHERE. IMAGE FRAGMENT FROM  
AERIAL COLOUR INFRARED PHOTOGRAPH. RGB COLOUR COM-  
POSITION IS ANALYSED. ROPME RS ARCHIVE.

### Lower

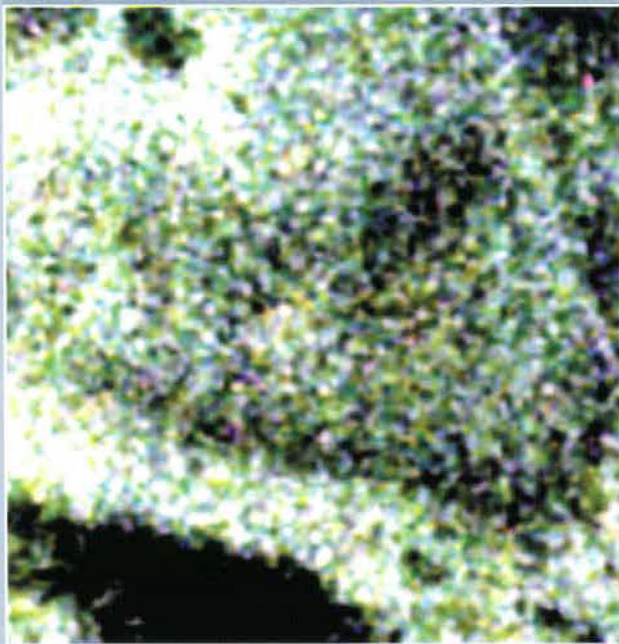
FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS  
SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE  
OF THE 3 CHANNELS OF THE ABOVE FRAGMENT IS SHOWN.

The high frequency groups are in the orthogonal  
direction to the main lineament - highway structure  
in the above fragment. The figure represents another  
typical "fingerprint" for artificial surface struc-  
tures. The white colour of the main frequency  
groups shows similar behavior in all channels (RGB  
presentation of FFT spectrum).





# STRUCTURAL ANALYSES OF DESERT SURFACE



## *Desert*

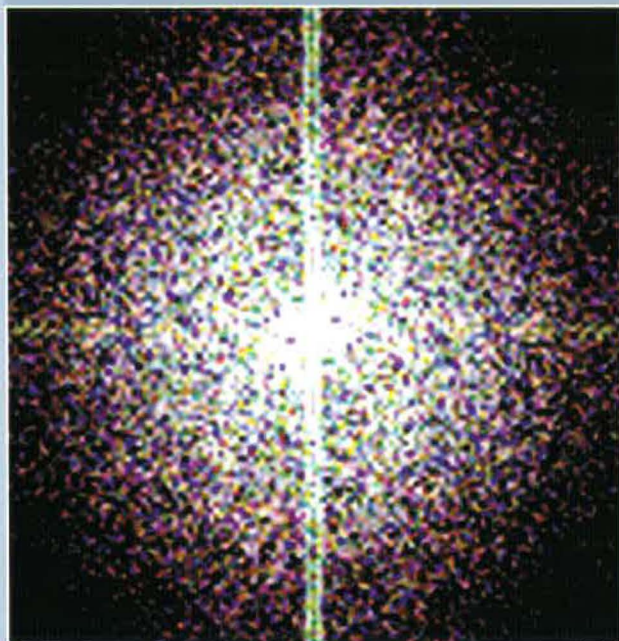
FRAGMENT OF IMAGE FROM THE DESERT SURFACE.  
AL - ZOUR AREA, KUWAIT

### *Upper*

RELATIVELY CLEAR ATMOSPHERE. IMAGE FRAGMENT  
FROM AERIAL COLOUR INFRARED PHOTOGRAPH WITH  
RGB COLOUR COMPOSITION IS ANALYSED. ROPME RS  
ARCHIVE.

### *Lower*

FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT  
IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAG-  
NITUDE OF THE 3 CHANNELS OF THE ABOVE FRAGMENT IS  
SHOWN.



The high frequency groups in the spectrum are in ran-  
dom directions, because no main lineaments in the  
above fragment. The figure represents another "finger-  
print" for natural surface structures in arid lands. The  
main power of the spectrum (white colour of main fre-  
quency group) shows similar behavior in all channels.



(RIGHT): ANALYSIS OF A FRAGMENT FROM NOAA / AVHRR IMAGE OF DESERT - MOUNTAIN INTERACTION NEAR THE BORDER OF UAE AND OMAN IN VARIOUS CHANNEL COMBINATIONS. FIGS.VII.2A, VII.2B AND VII.2C.

**FIG.VII.2A:** RIGHT IMAGE REPRESENTS RGB COLOUR COMPOSITION OF CH1, CH2 AND CH3. ROPME RS ARCHIVE. LEFT IMAGE REPRESENTS FFT POWER SPECTRUM OF THE FRAGMENT (RIGHT IMAGE).

The high frequency groups in the spectrum (left) are in groups in the orthogonal direction to the main orientation of nature lineaments in the above fragment (right). The figure represents another "fingerprint" of natural surface structures in the ROPME region. The main power of the spectrum (white colour of main frequency groups) shows similar behavior in all the channels (RGB presentation of FFT spectrum). Red, green and blue spots show the same behavior of distribution of the highest frequencies in the respective channels (ch1, ch2 and ch3).

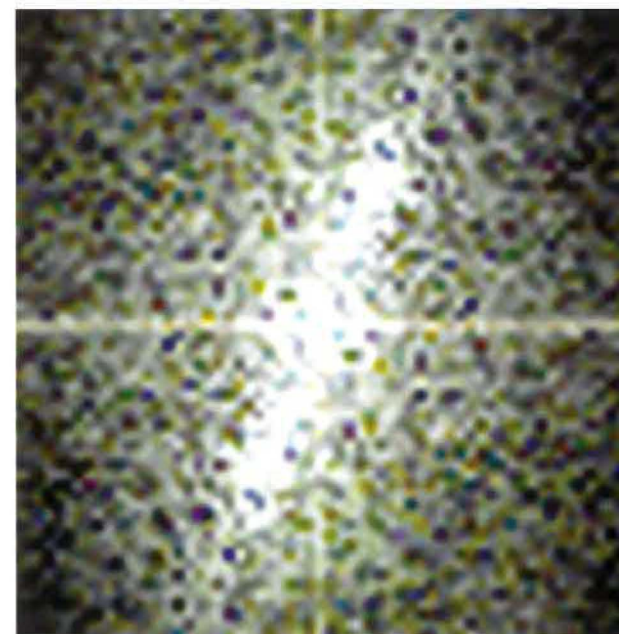
**FIG.VII.2B:** RIGHT IMAGE REPRESENTS RGB COLOUR COMPOSITION OF INFRARED PART: CH3, CH4 AND CH5. ROPME RS ARCHIVE. LEFT IMAGE REPRESENTS FFT POWER SPECTRUM OF THE FRAGMENT (RIGHT IMAGE).

The high frequency groups in the spectrum (left) are in groups in the orthogonal direction to the main orientation of nature lineaments in the above fragment (right). The figure represents another "fingerprint" of natural surface structures in the ROPME region. The main power of the spectrum (white colour of main frequency groups) shows similar behavior in all the TIR channels (RGB presentation of FFT spectrum). Red and reddish spots in the plot show the existence of higher frequencies in ch3 of the image.

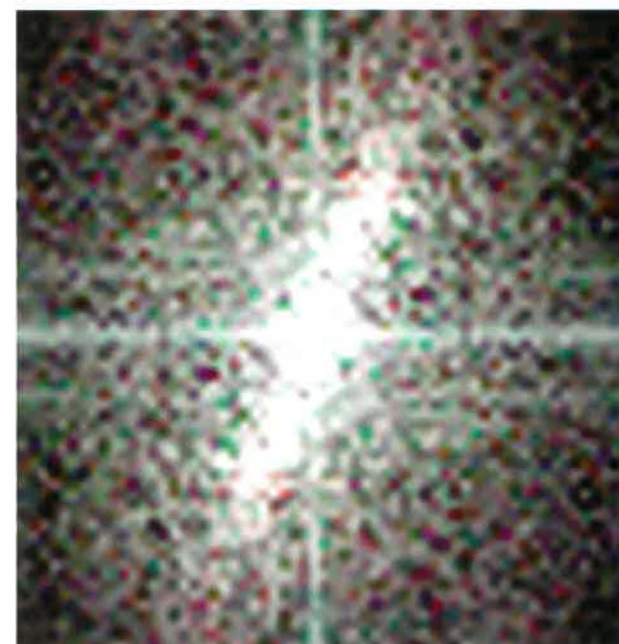
**FIG.VII.2C:** RIGHT IMAGE REPRESENTS RGB COLOUR COMPOSITION OF CH1, CH2 AND CH4. ROPME RS ARCHIVE. LEFT IMAGE REPRESENTS FFT POWER SPECTRUM OF THE FRAGMENT (RIGHT IMAGE).

The high frequency groups in the spectrum (left) are in groups in the orthogonal direction to the main orientation of nature lineaments in the above fragment (right). The figure represents another "fingerprint" of natural surface structures in the ROPME region. The main power of the spectrum (white colour of main frequency groups) shows similar behavior in all the channels (RGB presentation of FFT spectrum). Yellow spots in the plot show the existence of relatively higher frequencies in ch1, ch2, when compared to ch4 of the image.

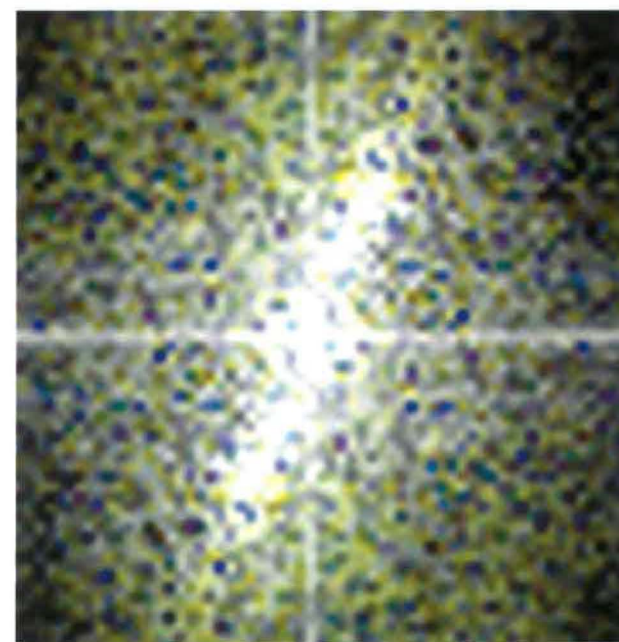
In general, the sharp shape of frequency groups is relatively less in FFT spectrum of natural objects when compared to artificial objects.



VII.2A



VII.2B



VII.2C



# ATMOSPHERIC EFFECTS ON STRUCTURAL ANALYSES

## *Estimation of atmosphere transparency and contrast transition through turbid atmosphere*

The high turbid atmosphere with soot and smog contamination from oil fire plumes products in the atmosphere over Kuwait City at noontime, acts as a low frequency filter for the reflected radiation from the Earth's surface.

Examples of fragments from aerial colour infrared photography taken in May 1991 are analysed below. The figures are in RGB colour composition, from ROPME RS archive.

Figs VII.3, VII.4 and VII.5 show the same spot observed in different angles. The shortest optical way (the smallest atmosphere mass) is observed on Fig VII.4 (Nadir - vertical direction).

Except for the atmosphere transmission function, it is possible to derive aerosol characteristics and spectral descriptions of aerosol indicators.



## *Turbid Atmosphere*

VII.3

CONTRAST TRANSITION THROUGH TURBID ATMOSPHERE.

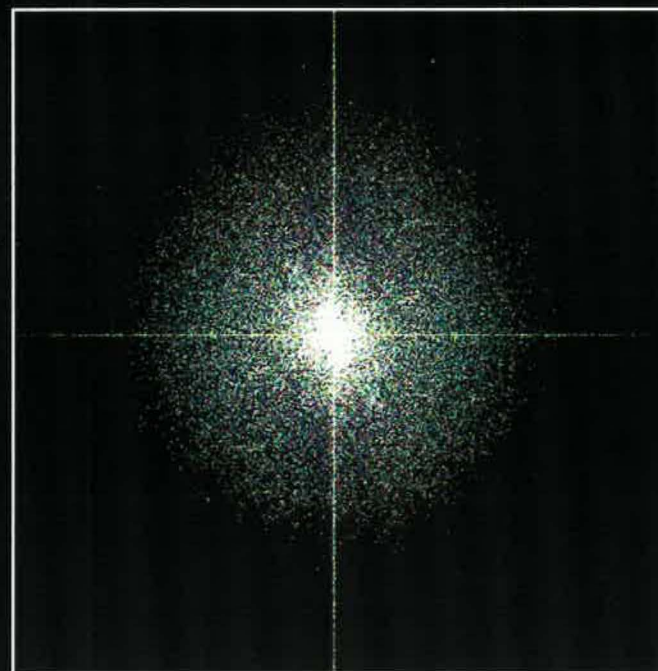
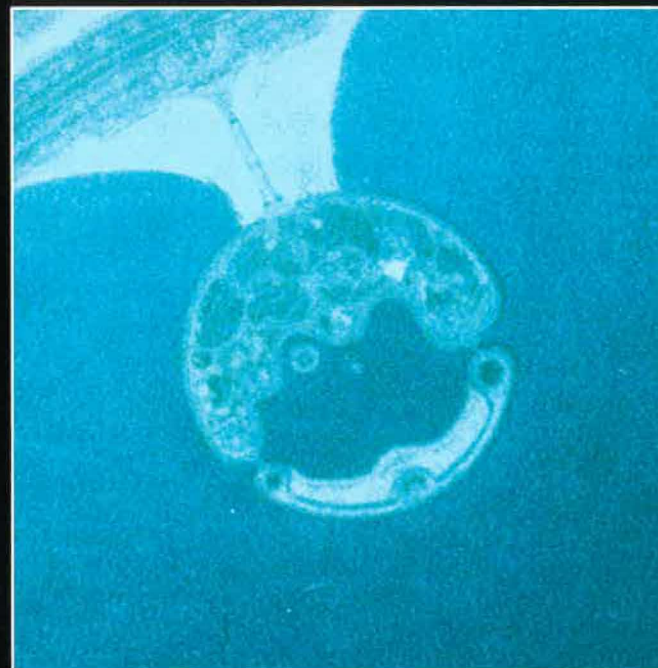
### *Upper*

HIGHLY TURBID ATMOSPHERE, SOOT AND SMOG CONTAMINATION OVER THE COAST IS OBSERVED. RGB COLOUR COMPOSITION OF THE IMAGE FRAGMENT FROM KUWAIT CITY IS SHOWN. OBLIQUE VIEW.

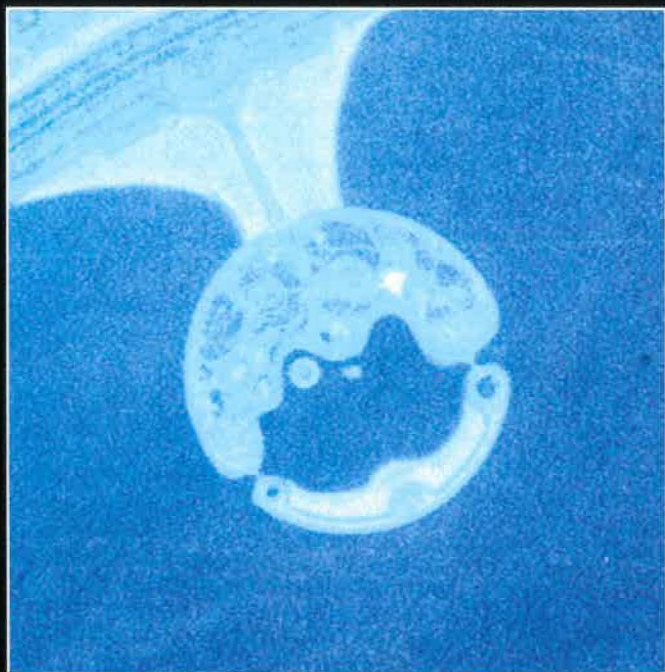
### *Lower*

FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF 3 CHANNELS OF ABOVE FRAGMENT IS SHOWN.

The main power spectrum is located in a relatively small central area (low frequency type). Less resolution is observed because of a larger optical way, which is acting as a low frequency filter.







## *Turbid Atmosphere*

VII.4

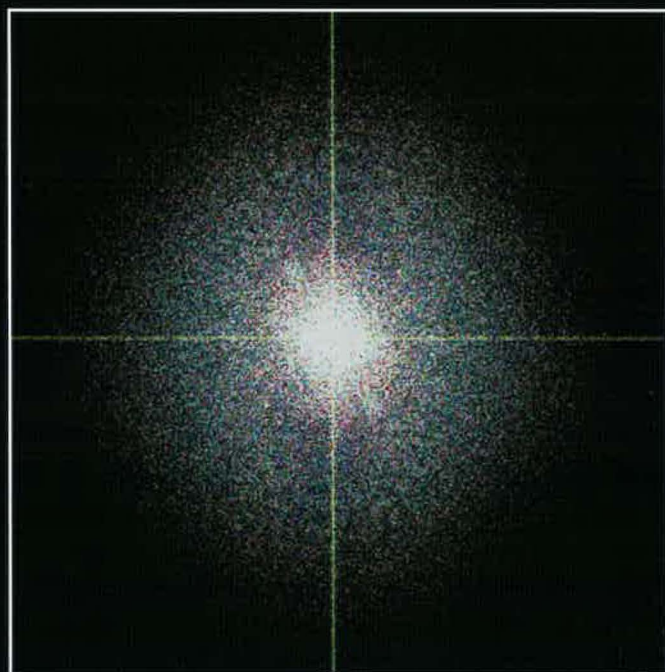
**CONTRAST TRANSITION THROUGH TURBID ATMOSPHERE.**

### *Upper*

**HIGHLY TURBID ATMOSPHERE, SOOT AND SMOG CONTAMINATION OVER THE COAST IS OBSERVED. RGB COLOUR COMPOSITION OF THE IMAGE FRAGMENT FROM KUWAIT CITY IS SHOWN. VIEW IN NADIR (VERTICAL DIRECTION).**

### *Lower*

**FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF 3 CHANNELS OF ABOVE FRAGMENT IS SHOWN.**



The main power spectrum is located in a relatively larger central area (more higher frequency type). It is possible to see some details in the spectrum, such as HF wings etc. Relatively higher resolution is observed because there is less optical way in comparison to Figs VII.3, and VII.5. Differences between these 3 types of spectrums (Figs VII.3 - VII.5) show the ability to differentiate between the specific features of atmosphere pollutant, such as the type of aerosol, etc.



## *Turbid Atmosphere*

VII.5

CONTRAST TRANSITION THROUGH TUR-  
BID ATMOSPHERE.

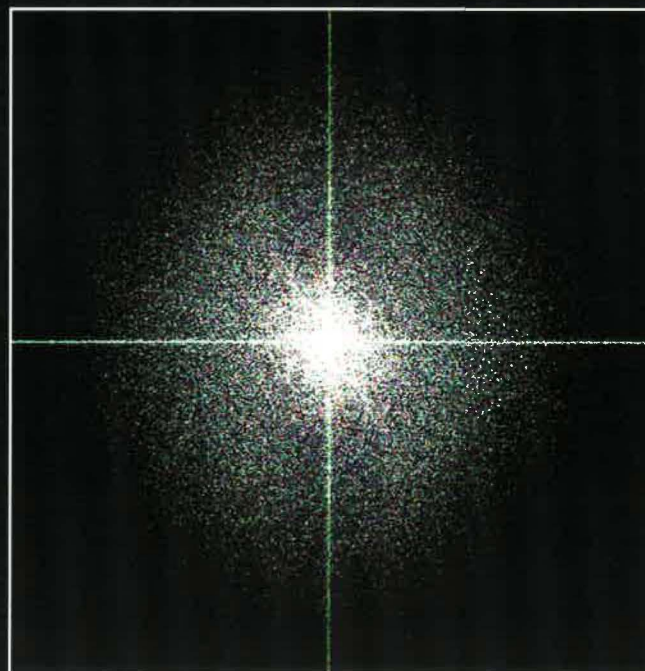
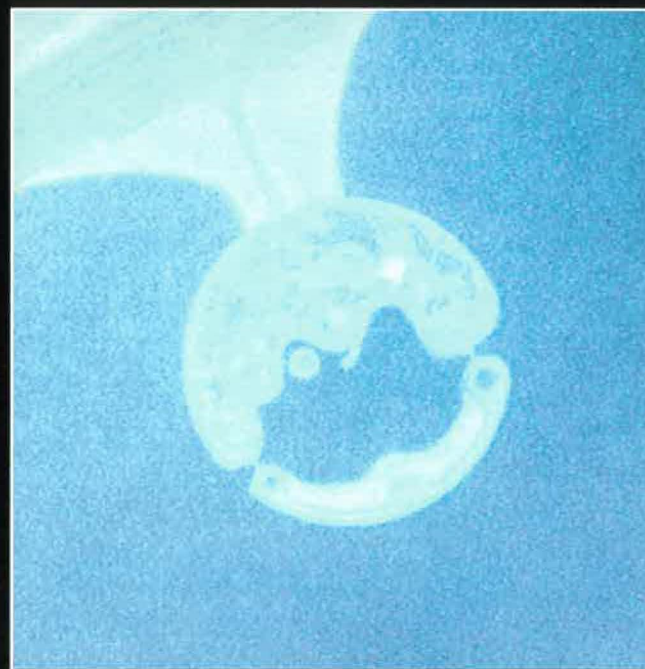
### *Upper*

HIGHLY TURBID ATMOSPHERE CAUSED BY SOOT AND SMOG  
CONTAMINATION OVER THE COAST IS OBSERVED. RGB  
COLOUR COMPOSITION OF THE IMAGE FRAGMENT FROM  
KUWAIT CITY IS SHOWN. OBLIQUE VIEW IS IN OPPOSITE  
DIRECTION IN COMPARISON TO FIG VII.3.

### *Lower*

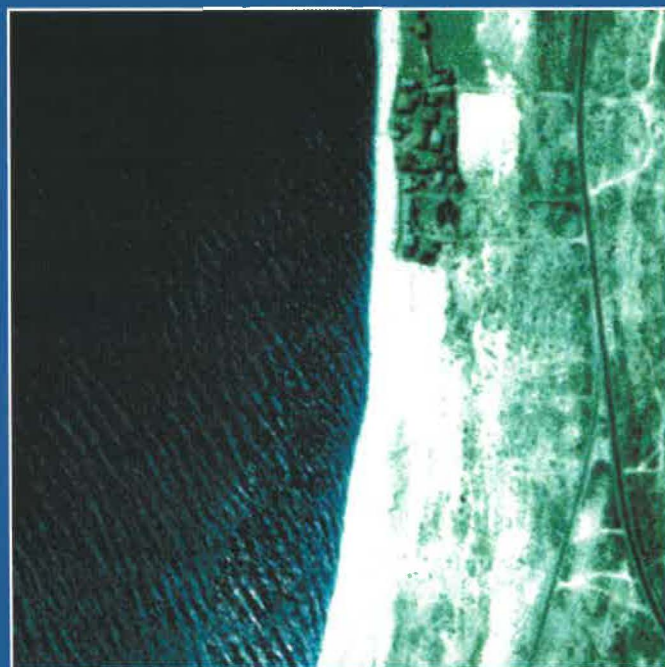
FFT POWER SPECTRUM OF THE ABOVE FRAGMENT IS  
SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNI-  
TUDE OF 3 CHANNELS OF THE ABOVE FRAGMENT.

Loss of contrast resolution in the image is due to a  
larger optical way, which is acting as a low frequen-  
cy filter. The main power spectrum is located in a  
relatively smaller central area when compared to  
Figure VII.4.





# STRUCTURAL ANALYSES OF COASTAL AREA



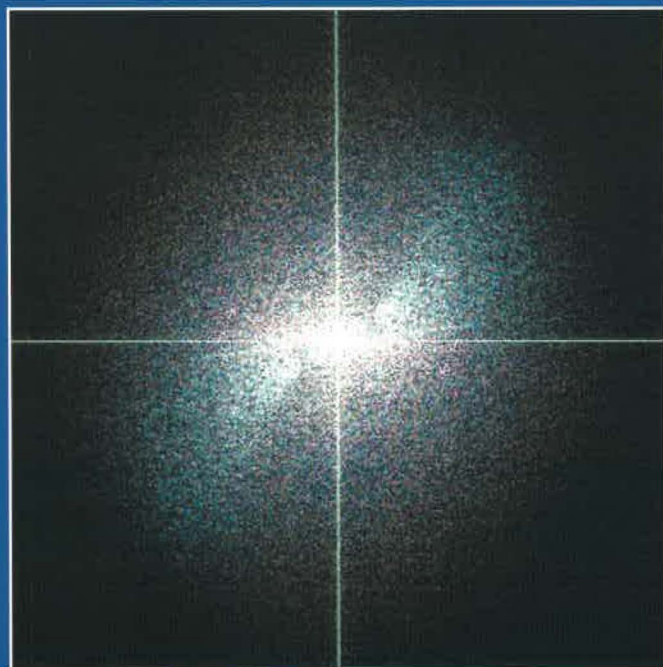
## *Relatively Clear Atmosphere*

VII.6

FRAGMENT OF IMAGE FROM AL - ZOUR COASTAL AREA, SOUTH OF KUWAIT. RELATIVELY CLEAR ATMOSPHERE.

## *Upper*

FRAGMENT FROM AERIAL COLOUR INFRARED PHOTOGRAPH. RGB COLOUR COMPOSITION OF THE IMAGE FRAGMENT FROM AL - ZOUR COASTAL AREA IN SOUTH KUWAIT. ROPME RS ARCHIVE.



## *Lower*

FFT POWER SPECTRUM OF THE ABOVE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF THE 3 CHANNELS OF THE ABOVE FRAGMENT IS SEEN.

The high frequency groups of the FFT spectrum, which represent the influence of sea waves, are grouped in wing patterns in the spectrum, in orthogonal directions to wind patterns in the image. The figure represents another "fingerprint" for natural surface structures in the coastal areas. The main power of the spectrum (white colours of main frequency group) shows similar behavior in all channels. Relatively higher frequencies are shown in blue, which corresponds to chl.



## *Relatively Clear Atmosphere*

VII.6  
LF

THE PREVIOUS IMAGE FRAGMENT (FIGURE VII.6), FROM AL - ZOUR COASTAL AREA, SOUTH OF KUWAIT, AFTER LOW FREQUENCY FILTRATION. RELATIVELY CLEAR ATMOSPHERE.

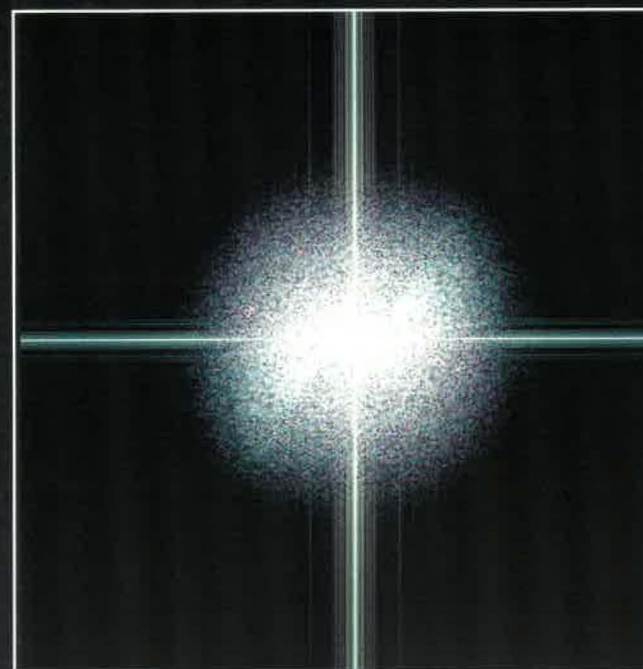
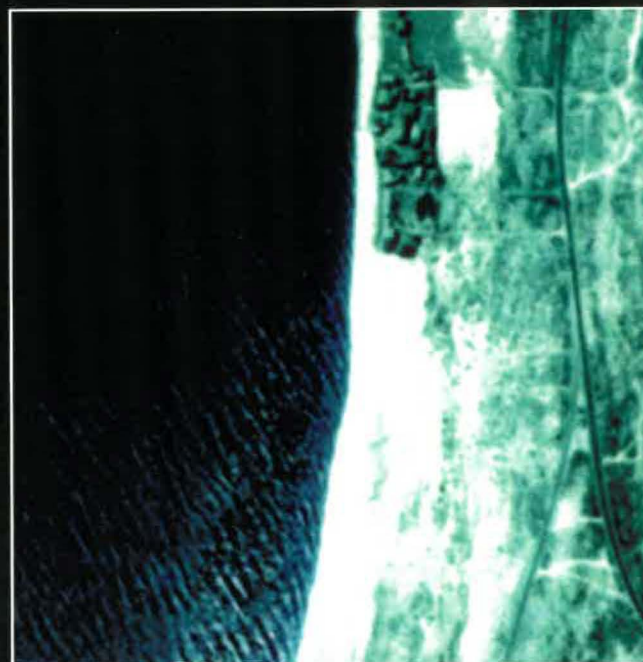
### *Upper*

RGB COLOUR COMPOSITION OF THE IMAGE FRAGMENT FROM AL - ZOUR COASTAL AREA IN SOUTH KUWAIT. FRAGMENT FROM AERIAL COLOUR INFRARED PHOTOGRAPH. ROPME RS ARCHIVE.

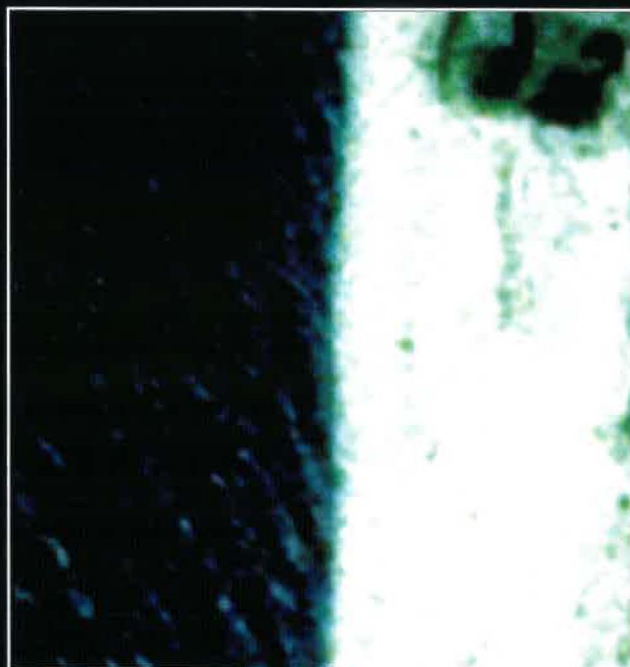
### *Lower*

FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF THE 3 CHANNELS OF THE ABOVE FRAGMENT IS SEEN.

Relatively fewer higher frequency groups are observed. The high frequency groups of the spectrum are grouped in wing patterns in orthogonal directions to wave patterns. The figure shows the effect of low frequency filtering (in terms of loss of resolution) on the image fragment. The main power of the spectrum (white colour of main frequency group) shows similar behavior in all channels, but central location (low frequency part) is relatively larger. RGB presentation of FFT spectrum is shown.







## *Relatively Clear Atmosphere*

VII.6  
TRANS

PART OF THE FRAGMENT FROM THE PREVIOUS COASTAL IMAGE FROM AL - ZOUR COASTAL AREA, SOUTH OF KUWAIT, IS SHOWN.

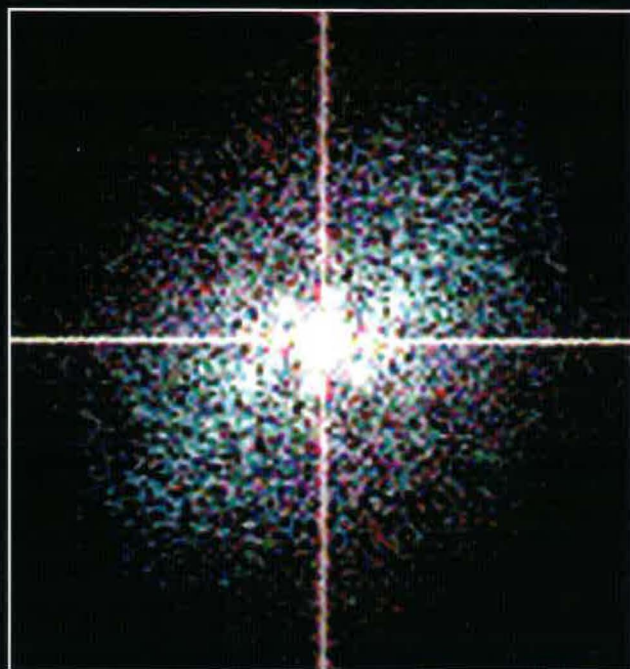
RELATIVELY CLEAR ATMOSPHERE.

## *Upper*

RGB COLOUR COMPOSITION OF COASTAL IMAGE FROM AL - ZOUR COASTAL AREA, SOUTH OF KUWAIT. IMAGE FRAGMENT FROM AERIAL COLOUR INFRARED PHOTOGRAPH. ROPME RS ARCHIVE.

## *Lower*

FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF THE 3 CHANNELS OF ABOVE FRAGMENT IS SEEN.



The lower resolution of FFT spectrum is observed because a smaller size of image fragment was analysed. High frequency groups are observed. High frequency groups (representing the influence of sea waves) are still grouped in small wing patterns in the spectrum, in orthogonal directions to wind patterns in the image. The figure shows a decrease of resolution because of the smaller size of the digital fragment. The main power of the spectrum (white colours of main frequency group) shows similar behavior in all channels.



## *Relatively Clear Atmosphere*



**RELATIVELY CLEAR ATMOSPHERE. THE PREVIOUS PART OF THE IMAGE FRAGMENT, FROM AL - ZOUR COASTAL AREA, SOUTH OF KUWAIT, AFTER LOW FREQUENCY FILTRATION IS SHOWN. .**

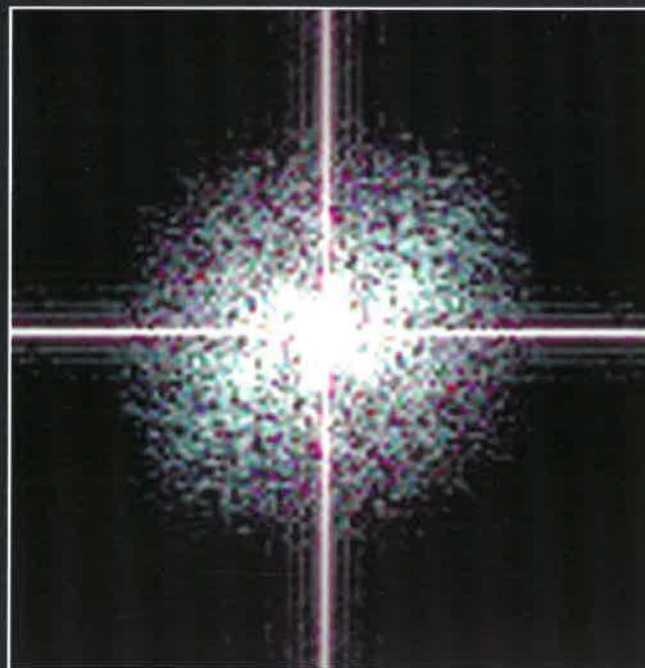
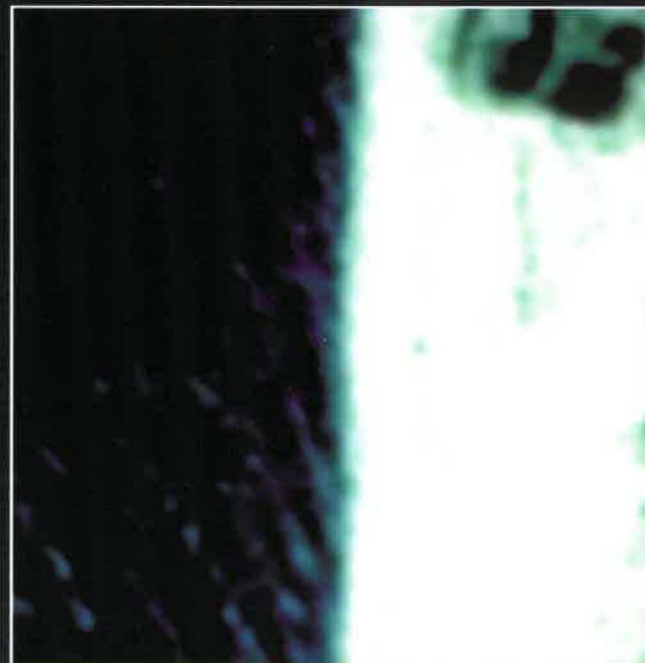
### *Upper*

**RGB COLOUR COMPOSITION OF THE IMAGE FRAGMENT, FROM AL - ZOUR COASTAL AREA, AFTER LOW FREQUENCY FILTRATION. IMAGE FRAGMENT FROM AERIAL COLOUR INFRARED PHOTOGRAPH. ROPME RS ARCHIVE.**

### *Lower*

**FFT POWER SPECTRUM OF THE ABOVE IMAGE FRAGMENT IS SHOWN. RGB COLOUR COMPOSITION OF FOURIER MAGNITUDE OF THE 3 CHANNELS OF THE ABOVE FRAGMENT IS SEEN.**

In addition to the lower resolution of FFT spectrum, relatively fewer high frequency groups are observed. The figure shows the effect of low frequency filtering (in terms of loss of resolution) and decrease in spectral domain resolution because of the smaller size of the image fragment. The main power of the spectrum (white colours of main frequency group) shows similar behavior in all channels







THE VALLEYS OF THE TIGRIS AND ZAB AL KABIR RIVERS. VEGETATION APPEARS IN RED, URBAN AREAS - IN BLuish-GREY. FARMING ACTIVITY APPEARS AS RECTANGULAR PLOTS IN THE ARABLE LAND IN THE UPPER LEFT PART OF THE IMAGE. IRRIGATED FARMING AREAS APPEAR ALONG THE RIVERS, WITH FRESH VEGETATION IN RED. ROUGH GRAZING AREAS AND NOMADIC HERDING AREAS ARE LOCATED IN THE LOWER LEFT PART OF THE IMAGE.

LANDSAT TM, 1999. RGB COLOUR COMBINATION OF BANDS 4, 3, 2.



**VIII. GEO INFORMATION SYSTEM  
ANALYSIS IN THE ROPME REGION**





IRAQ

KUWAIT

IRAN

BAHRAIN

SAUDI ARABIA

QATAR

U.A.E.

136



# BATHYMETRY, PORTS AND OIL ACTIVITY



# ROPME

RSA UP TO OMAN

# SEA AREA

VIII.1

BATHYMETRIC MAP OF ROPME  
SEA AREA. GULF OF OMAN TO  
SHATT AL-ARAB.

OMAN

## Legend



010 50 100 200

in Kilometers



# ROPME

COAST OF OMAN

# SEA AREA

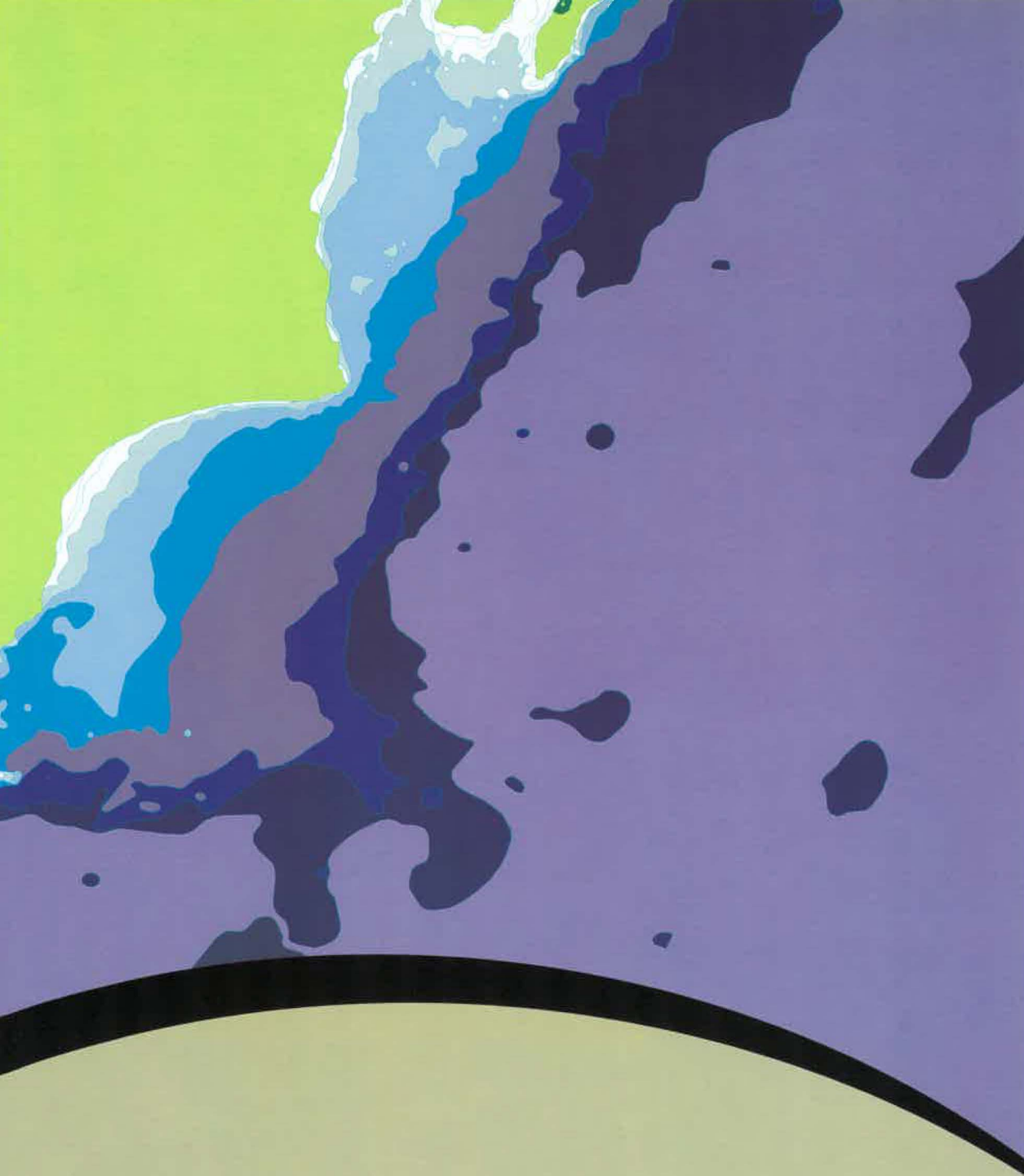
138

OMAN



## BATHYMETRY, PORTS AND OIL ACTIVITY



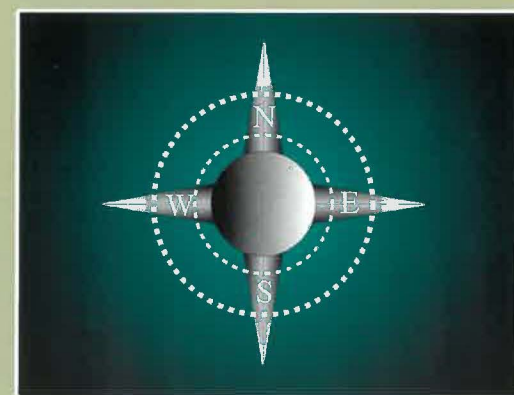


# Legend

|  |              |
|--|--------------|
|  | 2000m        |
|  | 1500m        |
|  | 1000m        |
|  | 500m         |
|  | 250m         |
|  | Land(0-250m) |
|  | 0            |
|  | -2m          |
|  | -5m          |
|  | -10m         |
|  | -20m         |
|  | -30m         |
|  | -50m         |
|  | -100m        |
|  | -200m        |
|  | -1000m       |
|  | -2000m       |
|  | -3000m       |
|  | -4000m       |
|  | -5000m       |
|  | -6000m       |
|  | Ports        |

VIII.2

BATHYMETRIC MAP OF ROPME SEA AREA,  
SOUTHEAST COAST OF ARABIAN PENINSULA.



010 50 100 200

in Kilometers





140



# BATHYMETRY, PORTS AND OIL ACTIVITY



# ROPME

RSA UP TO OMAN

# SEA AREA

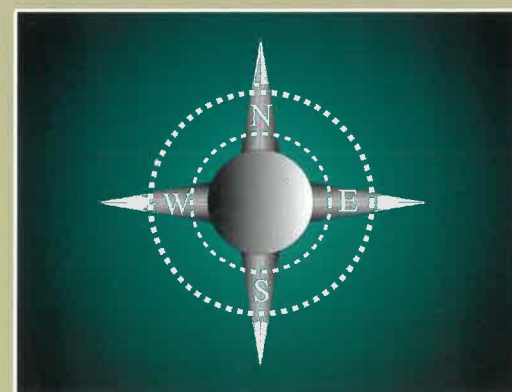
VIII.3

OIL INDUSTRY ACTIVITY IN THE ROPME SEA AREA SHOWING THE MAIN PORTS AND TERMINALS, PIPELINES\*, OIL FIELDS\* AND TANKER ROUTES\*, FROM GULF OF OMAN TO SHATT AL-ARAB. (\*EXCLUDING THE NORTHERN PART OF RSA).

OMAN

## Legend

- 2000m
- 1000m
- 500m
- Land(0-500m)
- 0m
- 10m
- 20m
- 30m
- 50m
- 100m
- 200m
- 1000m
- 2000m
- 3000m
- 5000m
- Port
- Oil Activity



in Kilometers





142



**DISTRIBUTION OF HABITATS AND POPULATIONS  
IN THE ROPME SEA AREA**



# ROPME

RSA UP TO OMAN

## SEA AREA

VIII.4

DISTRIBUTION OF SOME BIRD SPECIES  
IN ROPME SEA AREA FROM THE  
GULF OF OMAN UP TO SHATT AL-  
ARAB. THE AVAILABLE DATA IS FOR  
BAHRAIN, I.R. IRAN, KUWAIT, QATAR, SAUDI  
ARABIA AND UAE.

### Legend

-  Bridled Tern
-  White Cheeked Tern
-  Lessercrested Tern
-  Socotra's Cormorant
-  Birds of RSA

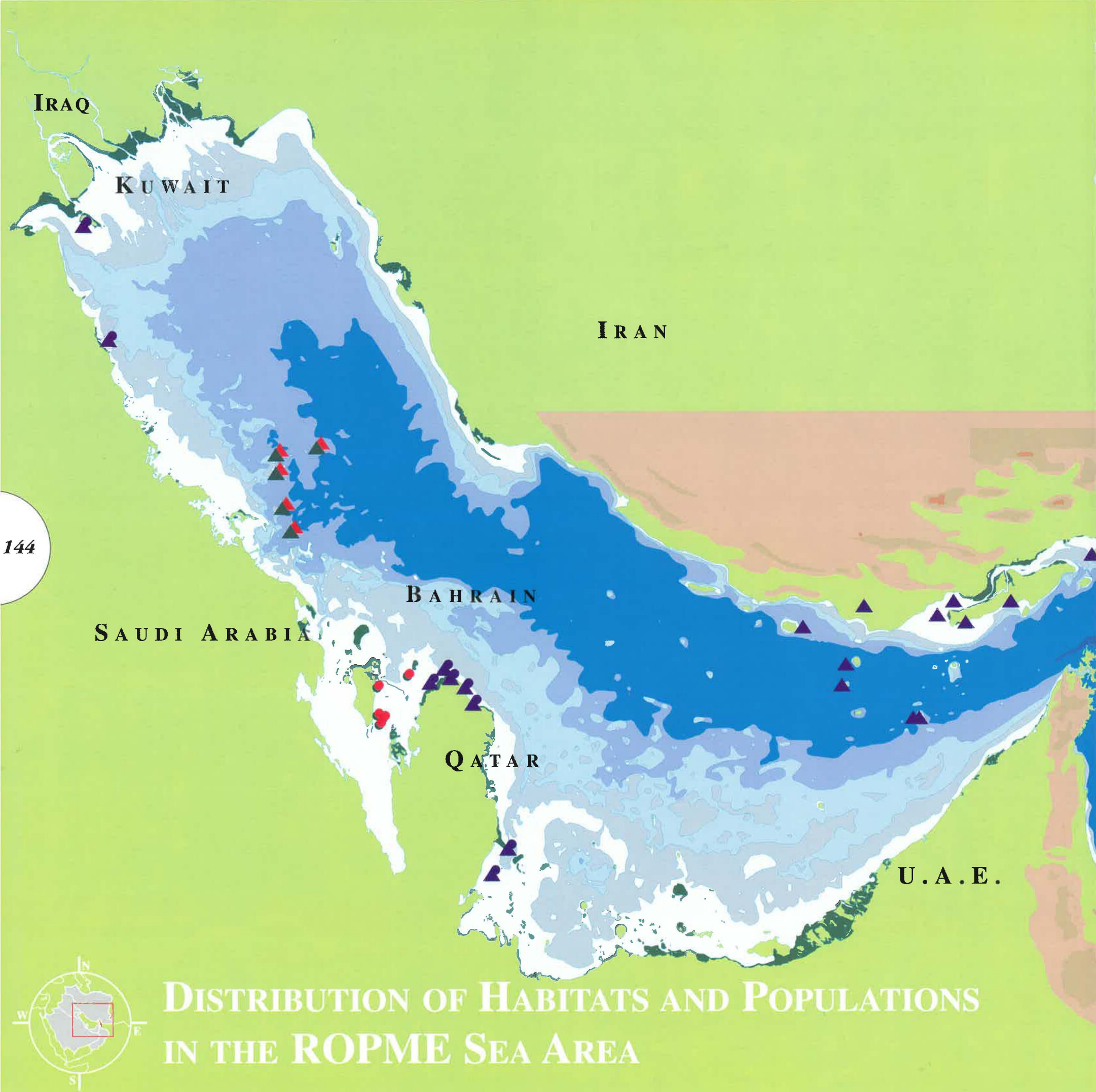


010 50 100 200

in Kilometers

OMAN







# ROPME

RSA UP TO OMAN

# SEA AREA

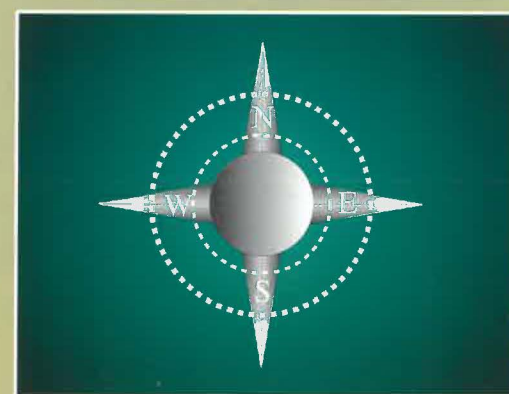
VIII.5

DISTRIBUTION OF SOME TURTLE SPECIES  
IN ROPME SEA AREA FROM THE GULF  
OF OMAN TO SHATT AL-ARAB. NESTING  
AREAS AND TURTLE DISTRIBUTION. THE  
AVAILABLE DATA IS FOR BAHRAIN, IRAN,  
KUWAIT, OMAN, QATAR AND SAUDI ARABIA.

OMAN

## Legend

- Turtle
- ▲ Nesting Area
- Green Turtle
- Hawksbill
- Turtles of RSA



010 50 100 200

in Kilometers

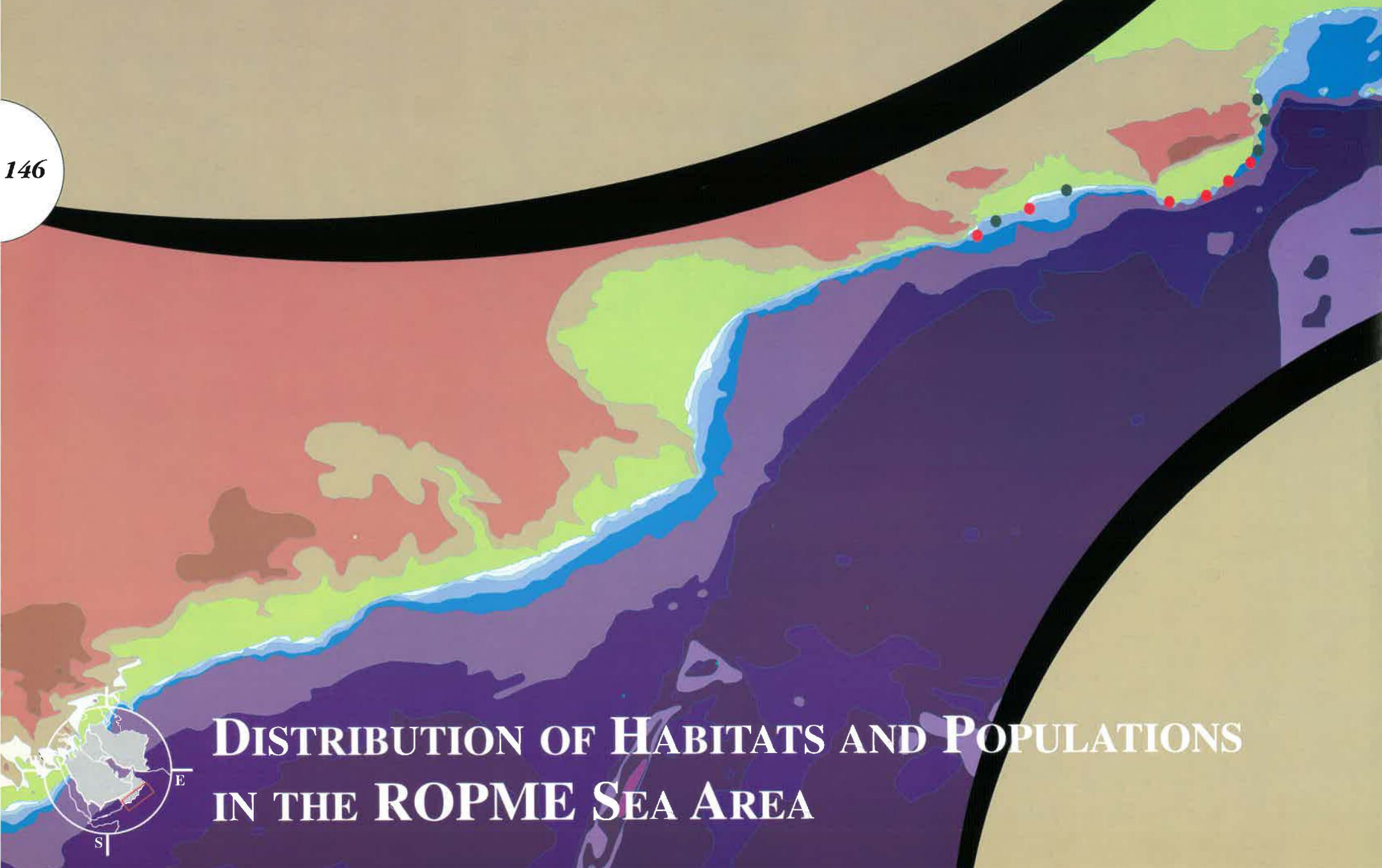


# ROPME

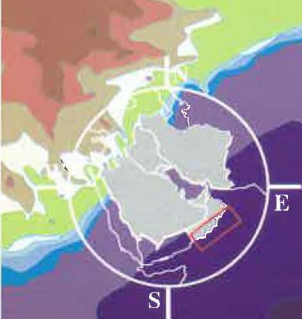
## COAST OF OMAN

# SEA AREA

146



# DISTRIBUTION OF HABITATS AND POPULATIONS IN THE ROPME SEA AREA





OMAN

# Legend

- Turtle
- ▲ Nesting Area
- Green Turtle
- Loggerhead
- Olive ridley
- Turtles of RSA



010 50 100 200  
in Kilometers

VIII.6  
DISTRIBUTION OF SOME TURTLE SPECIES IN ROPME SEA  
AREA. NESTING AREAS AND TURTLE DISTRIBUTION IN OMAN  
AND THE SOUTHEAST COAST OF ARABIAN PENINSULA.





**DISTRIBUTION OF HABITATS AND POPULATIONS  
IN THE ROPME SEA AREA-SENSITIVITY**



# ROPME

RSA UP TO OMAN

## SEA AREA

VIII.7

ASSESSMENT ANALYSIS (SENSITIVITY).  
RELATIONSHIP OF PORT ACTIVITY AND TURTLE  
HABITATS IN COASTAL WATERS OF  
ROPME SEA AREA.

DISTRIBUTION OF OIL PORTS AND SURROUNDING  
AREAS (WITHIN RADIUS OF 30 KM) AND TURTLE HABI-  
TATS (WITHIN A RADIUS OF 30 KM) ON THE SEA WITH  
A DEPTH OF UPTO 10 M.

OMAN

### Legend



Port



Turtle



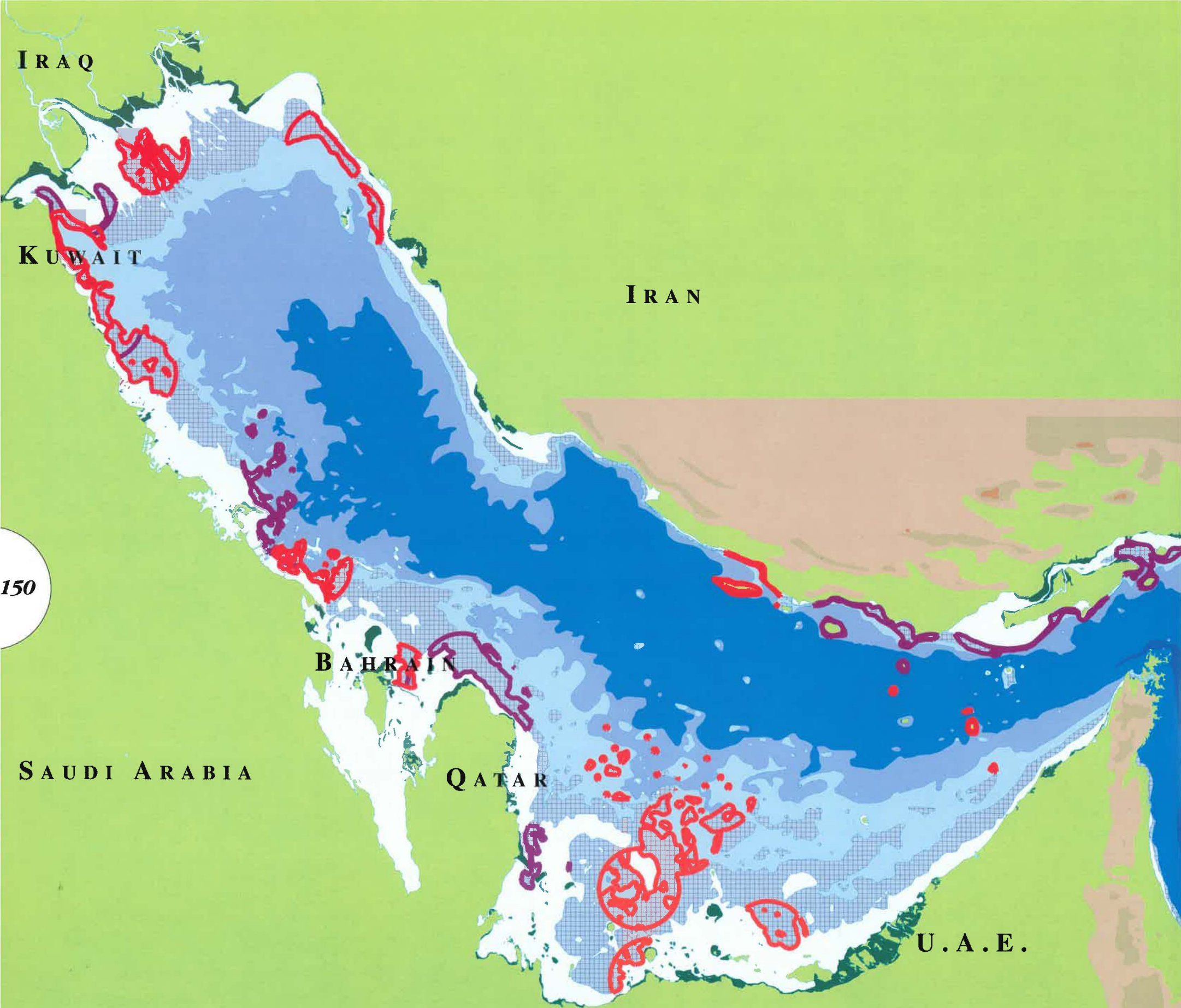
Sea Depth, 10m



010 50 100 200

in Kilometers





# DISTRIBUTION OF HABITATS AND POPULATIONS IN THE ROPME SEA AREA-SENSITIVITY



# ROPME

RSA UP TO OMAN

# SEA AREA

VIII.8

ASSESSMENT ANALYSIS (SENSITIVITY).  
RELATIONSHIP OF PORT ACTIVITY AND TURTLE  
HABITATS IN COASTAL WATERS OF  
ROPME SEA AREA.

DISTRIBUTION OF OIL PORTS AND SURROUNDING  
AREAS (WITHIN A RADIUS OF 30 KM) AND TURTLE  
HABITATS (WITHIN RADIUS OF 30 KM) ON THE SEA  
WITH A DEPTH OF 10 TO 20 M.



## Legend



Port



Turtle



Sea Depth, 20m



010 50 100 200

in Kilometers





152



# DISTRIBUTION OF HABITATS AND POPULATIONS IN THE ROPME SEA AREA



# ROPME

RSA UP TO OMAN

# SEA AREA

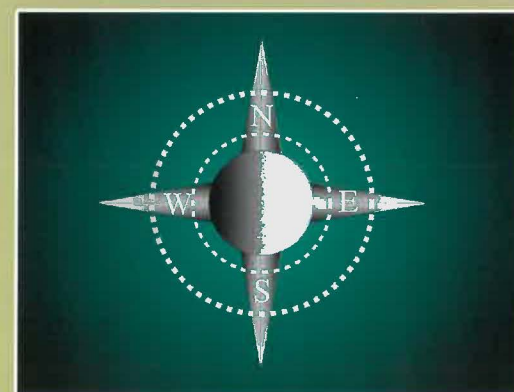
VIII.9

DISTRIBUTION OF DUGONGS POPULATION IN  
ROPME SEA AREA, FROM THE GULF OF  
OMAN UP TO SHATT AL-ARAB.

OMAN

## Legend

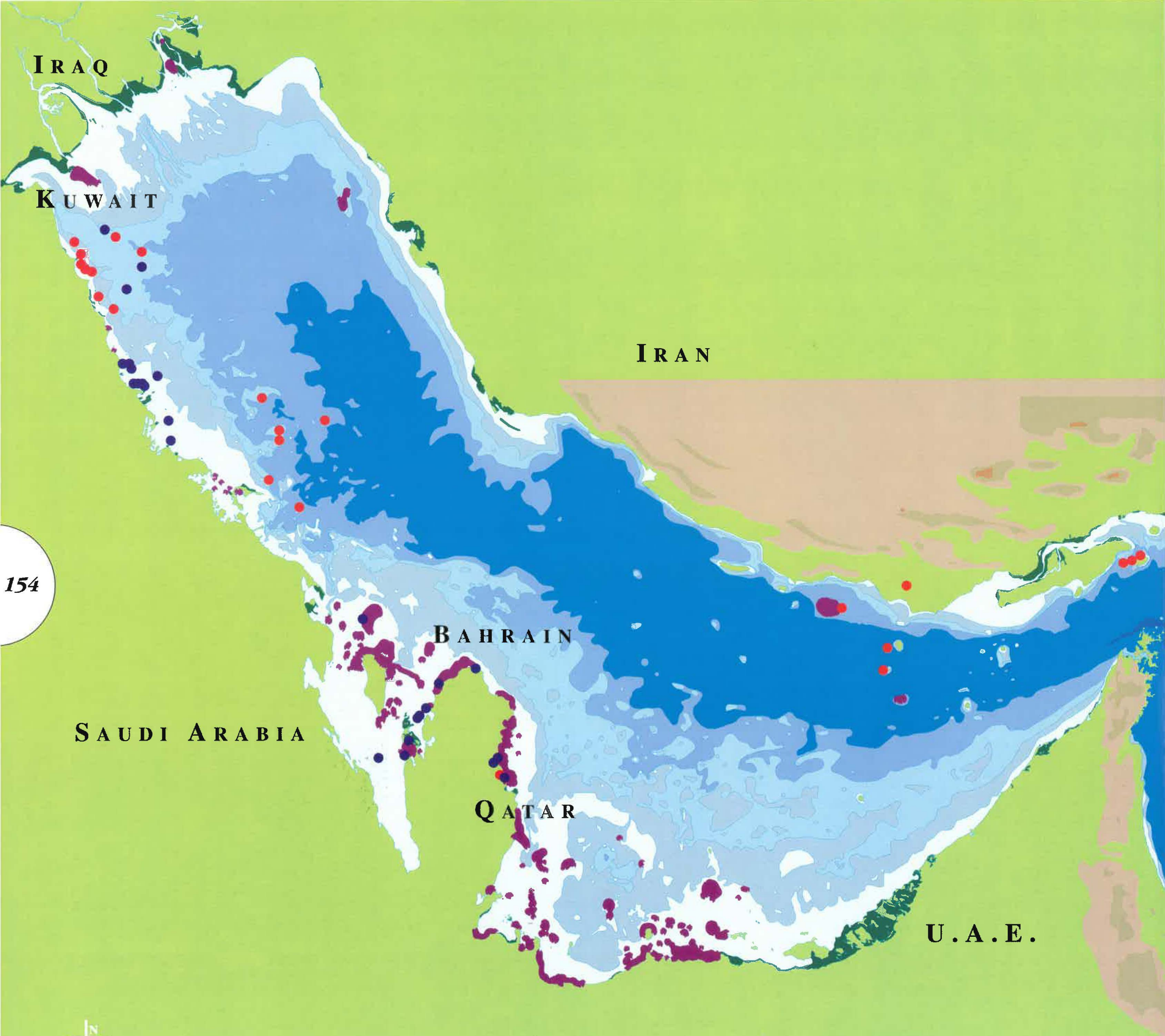
 Dugong



010 50 100 200

in Kilometers





## DISTRIBUTION OF HABITATS AND POPULATIONS IN THE ROPME SEA AREA-CORAL REEFS



# ROPME

RSA UP TO OMAN

## SEA AREA

VIII.10

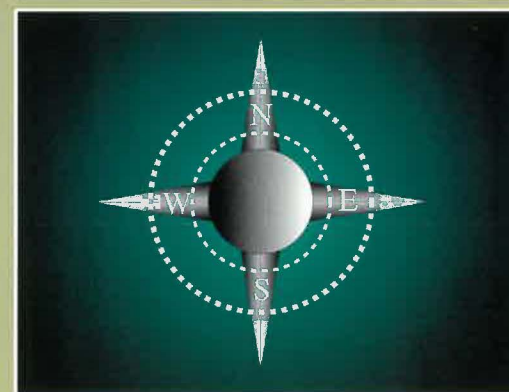
DISTRIBUTION OF SOME CORAL REEFS IN  
ROPME SEA AREA, GULF OF OMAN TO  
SHATT AL-ARAB.

THE AVAILABLE DATA IS FOR BAHRAIN, I.R.  
IRAN, KUWAIT, QATAR, AND SAUDI ARABIA.

OMAN

### Legend

-  Coral Reef
-  Island  
Surrounded  
by Coral Reef
-  Coral Region



010 50 100 200

in Kilometers





ATMOSPHERIC - OCEAN INTERAC-  
TION. CLOUD DISTRIBUTION NEAR  
THE STRAIT OF HORMUZ. BLUE  
REPRESENTS SHALLOW WATERS,  
WHITE REPRESENTS THE LAND  
SURFACE AND CLOUDS.





# ABBREVIATIONS

**AATSR** Advanced Along Track Scanning Radiometer (AATSR) instrument on the ESA POEM-1 polar platform mission. The AATSR is a direct development of the ATSR-1 (Along Track Scanning Radiometer) instrument, which is currently operating on the ESA/ERS-1 (Earth Resources Satellite) and ATSR-2, which was launched on ERS-2 in January 1995.

**ADEOS** Advanced Earth Observation Satellite, NASDA, Japan.

**AMI** Active Microwave Instrument, ERS.

**ASAR** An Advanced Synthetic Aperture Radar (ASAR), operating at C-band. ASAR ensures continuity with the image mode SAR and the wave mode of the ERS-1/2 AMI.

**ASTER** Advanced Spaceborne Thermal Emission and Reflection Radiometer, EOS AM-1 satellite, NASA.

**ATSR** Along Track Scanning Radiometer, ERS.

**AVHRR** Advanced Very High Resolution Radiometer. The Advanced Very High Resolution Radiometer (AVHRR) is a broad-band, four or five channel (depending on the model) scanner, sensing in visible, near-infrared, and thermal infrared region. This sensor is carried on NOAA's Polar Orbiting Weather Satellites, since 1978.

**AVIRIS** Airborne Visible InfraRed Imaging Spectrometer.

**CNES** Centre National d'Etudes Spatiales, France.

**CZCS** Coastal Zone Colour Scanner.

**DEM** Digital Elevation Model.

**DMS** Dimethylsulphide.

**DMSP** Defense Meteorological Satellite Program.

**DORIS** Doppler Orbitography and Radiopositioning Integrated by Satellite is a tracking system providing range-rate measurements of signals from a dense network of ground-based beacons. This data is precision processed on ground, providing the satellite orbit with accuracy of several centimeters. They are also processed on board to provide real-time satellite positions with an accuracy of some tens of centimeters.



# ABBREVIATIONS

**ENVISAT** Envisat-1 is a satellite dedicated for studying the Earth and atmosphere environment. Envisat-1 is a multidisciplinary mission, having both scientific and application objectives, continuing and extending the ERS-1 and ERS-2 mission objectives, and building up a coherent European Earth observation programme. In June 2001, the European Space Agency will launch Envisat-1, an advanced polar-orbiting Earth observation satellite which will provide measurements of the atmosphere, ocean, land, and ice over a five year period. The Envisat-1 satellite has an ambitious and innovative payload that will ensure the continuity of the data measurements of the ESA's ERS satellites. The Envisat-1 data will support Earth science research and allow monitoring of the evolution of environmental and climatic changes.

**EOS** The Earth Observing System (EOS) is intended to conduct long-term global observations of the Earth's land surface, atmosphere, oceans, and biosphere. EOS is the centerpiece of NASA's Mission to Planet Earth (MTPE), and together with other missions from NOAA, Europe, and Japan forms the comprehensive International Earth Observing System (IEOS). Using data from the first EOS satellite and missions that follow it, scientists will be able to create predictive computer models of the Earth's environment that will help us anticipate climate changes and better prepare for them.

**ERS** European Remote-Sensing Satellite. ERS-1 Satellite (1992) The satellite concept is based on the re-utilisation of the Multi-mission Platform, developed within the French SPOT programme, respectively launched in 1992 and 1995 the ERS-1 and ERS-2 satellites are an ESA success. ERS-2, the European Space Agency's second environmental satellite is the most complex satellite ever built in Europe to observe planet Earth and its environment.

**ERTS** On July 23, 1972, NASA launched the first in a series of Landsat satellites designed to provide repetitive global coverage of the Earth - the "Earth Resources Technology Satellite - A". When operational orbit was achieved, it was designated "ERTS-1". The satellite continued to function beyond its designed life expectancy of 1 year and finally ceased to operate on January 6, 1978, more than 5 years after its launch date.

**ESA** European Space Agency.

**ESE** Earth Sciences Enterprise, NASA's Program.

**ETM / LANDSAT** Enhanced Thematic Mapper Plus (ETM+). Equipped with high resolution instruments, Landsat-7 was successfully launched on April 15, 1999. This satellite carries the Enhanced Thermal Mapper Plus (ETM+) which is an eight-band, multispectral scanning radiometer. The ETM+ is capable of resolving distances of 15 meters in the panchromatic band; 30 meters in the visible, near and short-wave infrared band; and 60 meters in the thermal infrared band.



# ABBREVIATIONS

**GAC** Global Area Coverage data.

**GCM** Global Climate Model.

**GIS** Geo Information System.

**GOCE** Gravity Field and Steady-state Ocean Circulation Explorer, ESA. The focus of attention is GOCE, the Gravity Field and Steady State Ocean Circulation Explorer mission of ESA. GOCE is one of the four candidate missions within the Earth Explorer Program and the first dedicated gravity field mission of ESA. GOCE has a long history, which is very well documented by a series of investigations, primarily made under the CIGAR I to IV projects.

**GOCM** Global Ocean Circulation Models.

**GOMOS** The Global Ozone Monitoring by Occultation of Stars (GOMOS) Instrument on board Envisat-1 is the latest ESA instrument aimed at ozone monitoring. It is a tool to provide altitude-resolved global ozone mapping and trend monitoring with the high accuracy needed for understanding ozone chemistry and for model validation.

**GRID** Global Resource Information Database.

**HIRIS** High Resolution Imaging Spectrometer.

**HRPT** High Resolution Picture Transmission mode.

**HRV / SPOT** SPOT's HRV imaging payload provides 20 meter resolution multispectral imagery and 10 meter panchromatic imagery using push-broom sensors. HRV covers the following spectral bands: 0.5 - 0.59  $\mu\text{m}$ , 0.61 - 0.68  $\mu\text{m}$ , 0.79 - 0.89  $\mu\text{m}$ ; in addition to the panchromatic band: 0.51 - 0.73  $\mu\text{m}$ . The field of view is 4.13° in both modes (multispectral and panchromatic) with 3000 pixels per multispectral line and 6000 pixels per panchromatic line.

**IEOS** International Earth Observing System, NASA's Mission to Planet Earth.

**IR** Infrared.

**JASON-1** The Jason -1 is an oceanography mission to monitor global ocean circulation, discover the tie between the oceans and atmosphere, improve global climate predictions and monitor events such as El Nino conditions and ocean eddies.



# ABBREVIATIONS

**km** Kilometer.

**LAC** Local Area Coverage data.

**LANDSAT** On July 23, 1972, NASA launched the first in a series of satellites designed to provide repetitive global coverage of the Earth's land masses. It was designated initially as the "Earth Resources Technology Satellite-A". The second in this series of Earth resources satellites (designated "ERTS-B") was launched January 22, 1975. It was renamed "Landsat 2" by NASA, which also renamed "ERTS-1" as "Landsat 1." Four additional Landsats were launched in 1978, 1982, 1984 and 1999 (Landsat 3, 4, 5 and 7).

**LRR** The Laser Retro-reflector (LRR) is a passive device, which will be used in the future as a reflector by ground-based SLR stations using high-power pulsed lasers.

**MERIS** The MEdium Resolution Imaging Spectrometer is a 68.5° field-of-view pushbroom imaging spectrometer that measures the solar radiation reflected by the Earth, at a ground spatial resolution of 300m, in 15 spectral bands, programmable in width and position, in the visible and near infra-red. MERIS allows global coverage of the Earth in 3 days.

**METEOSAT** Geosynchronous Meteorology Satellite (ESA).

**METOP** The MetOp (Meteorological Operational) satellites will carry instruments provided by ESA, Eumetsat, NOAA and the French space agency CNES. Several improvements, namely an enhanced platform, an ameliorated on-board recording capability, a better communication system and a greater payload capability, will ensure that the MetOp satellites will offer better performance than the current NOAA system.

**μm** Micrometer.

**MIPAS** The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is a Fourier transform spectrometer for the measurement of high-resolution gaseous emission spectra at the Earth's limb. It operates in near to mid infrared, where many of the atmospheric trace-gases play a major role in atmospheric chemistry.

**MODIS** Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the TERRA satellites. MODIS will view the entire Earth's surface every 1 to 2 days. The MODIS Proto-Flight Model (PFM) was successfully launched from Vandenberg Air Force Base, CA on December 18, 1999 aboard the satellite.

**MOS** Marine Observation Satellite, NASDA, Japan.



# ABBREVIATIONS

**MSS / LANDSAT** Multispectral Scanner, Landsat.

**MTPE** Mission to planet Earth, NASA programme.

**MWR** The main objective of the MicroWave Radiometer (MWR) is the measurement of the integrated atmospheric water vapour column and cloud liquid water content, as correction terms for the radar altimeter signal. In addition, MWR measurement data are useful for the determination of surface emissivity and soil moisture over land, for surface energy budget investigations to support atmospheric studies, and for ice characterization.

**NASA** National Aeronautics and Space Administration, USA.

**NASDA** National Space Development Agency, Japan.

**NDVI** Normalized Difference Vegetation Index (NDVI), is calculated from the reflected solar radiation in the near-infrared (NIR) and red (RED) wavelength bands.

**NIMBUS** NOAA's Polar Orbiting Satellite Systems.

**NIR** Near Infrared.

**nm** Nanometer.

**NOAA** National Oceanic and Atmospheric Administration, USA.

**NRL** Naval Research Laboratory, USA.

**NW** Northwest.

**PM / SPOT** SPOT 's HRV 10 meter panchromatic imagery using push-broom sensors.

**POSEIDON** CNES, Solid state radar altimeter, Ocean Topography Experiment Poseidon (NASA- CNES).

**pxl** Pixel - picture element.

**RA** Radar Altimeter, ERS



# ABBREVIATIONS

**RA-2** The Radar Altimeter 2 (RA-2) is an instrument for determining the two-way delay of radar echo from the Earth's surface to a very high precision (less than a nanosecond). It also measures the power and the shape of the reflected radar pulses. The RA-2 is derived from the ERS-1 and 2 Radar Altimeters, providing improved measurement performance and new capabilities. Operating over oceans, its measurements are used to determine the ocean topography, thus supporting the research of ocean circulation, bathymetry and marine geoid characteristics. Furthermore, the RA-2 is able to map and monitor sea ice, polar ice sheets, and most land surfaces. Measurement of the radar echo power and shape enables the determination of wind speed and significant wave height at sea, thus supporting weather and sea state forecasting.

**RADARSAT** The RADARSAT satellite is a project of the Canadian Space Agency.

**RBV** A three-channel, or three-band, Return Beam Vidicon (RBV), Landsat.

**ROPME** Regional Organization for the Protection of the Marine Environment.

**RS** Remote Sensing.

**RSA** ROPME Sea Area.

**SAR** Synthetic Aperture Radar.

**SCIAMACHY** The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartography (SCIAMACHY) is one of the Announcement of Opportunity payload instruments embarked on board the ESA Envisat-1 satellite to be launched with GOME (Global Ozone Measurement Experiment).

**SEASAT** Specialized Experimental Applications Satellite was a NASA satellite launched in 1978 to study the oceans. It pioneered the use of orbiting radar to measure ocean waves and currents.

**SeaWiFS** The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) project provides quantitative data on global ocean bio-optical properties.

**SIR-C/X-SAR** Space-borne Imaging Radar-C/X-band Synthetic Aperture Radar is a joint project of the National Aeronautics and Space Administration (NASA), the German Space Agency (DARA) and the Italian Space Agency (ASI). Data are collected in L-Band and C-Band by SIR-C, and X-Band by X-SAR.



# ABBREVIATIONS

**SPOT** Satellite Probatoire d'Observation de la Terre. The SPOT satellites' two viewing instruments (HRVS) when operated simultaneously in the vertical viewing configuration are capable of imaging a 117 km wide strip on the Earth's surface. SPOT XS (multispectral) instrument Satellite Probatoire d'Observation de la Terre. CNES, ESA, SPOT-Image Corp.

**SST** Sea Surface Temperature.

**TERRA** The TERRA Project (formally known as AM-1) was responsible for the design, fabrication, test, launch, and on-orbit checkout of the instruments and spacecraft for the first EOS mission. TERRA was successfully launched on December 18, 1999. The TERRA mission is part of NASA's Earth Sciences Enterprise (ESE).

**TIR** Thermal Infrared.

**TIROS** NOAA -TIROS, Television and Infrared Observation Satellite.

**TM / LANDSAT** The biggest technological improvement in post-Landsat 3 imaging system is the incorporation of the Thematic Mapper (TM), an advanced sensor that includes spectral, radiometric, and geometric design improvements.

**TOPEX** NASA's Operational Altimeter, Ocean Topography Experiment (NASA- CNES).

**TOPEX / POSEIDON** Ocean Topography Experiment Poseidon (NASA- CNES).

**UHI** Urban Heat Island Effects.

**UNEP** United Nations Environment Programme.

**VNIR** Visible and Near Infrared.

**XS / SPOT** SPOT 's HRV 20 meter resolution multispectral imagery using push-broom sensors.



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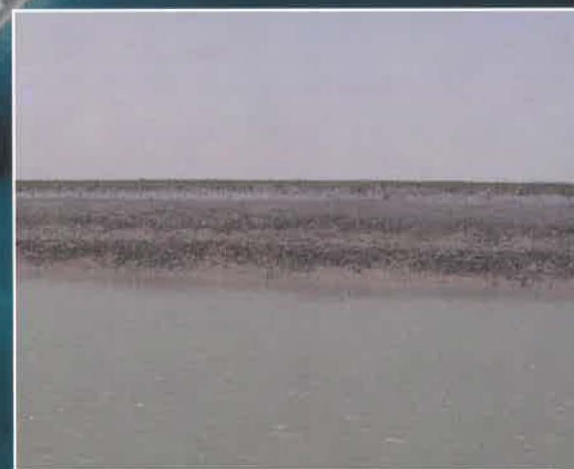
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MUDFLAT, THE BUBIAN ISLAND, KUWAIT.  
VEGETATION APPEARS AS REDDISH.  
MERGING IMAGES HAVE PANCHROMATIC  
(15 M/PXL) AND RGB COLOUR COMPOSI-  
TION (BANDS 4, 3, AND 2, 30M/PXL).  
LANDSAT 7 ETM, 2000.

170



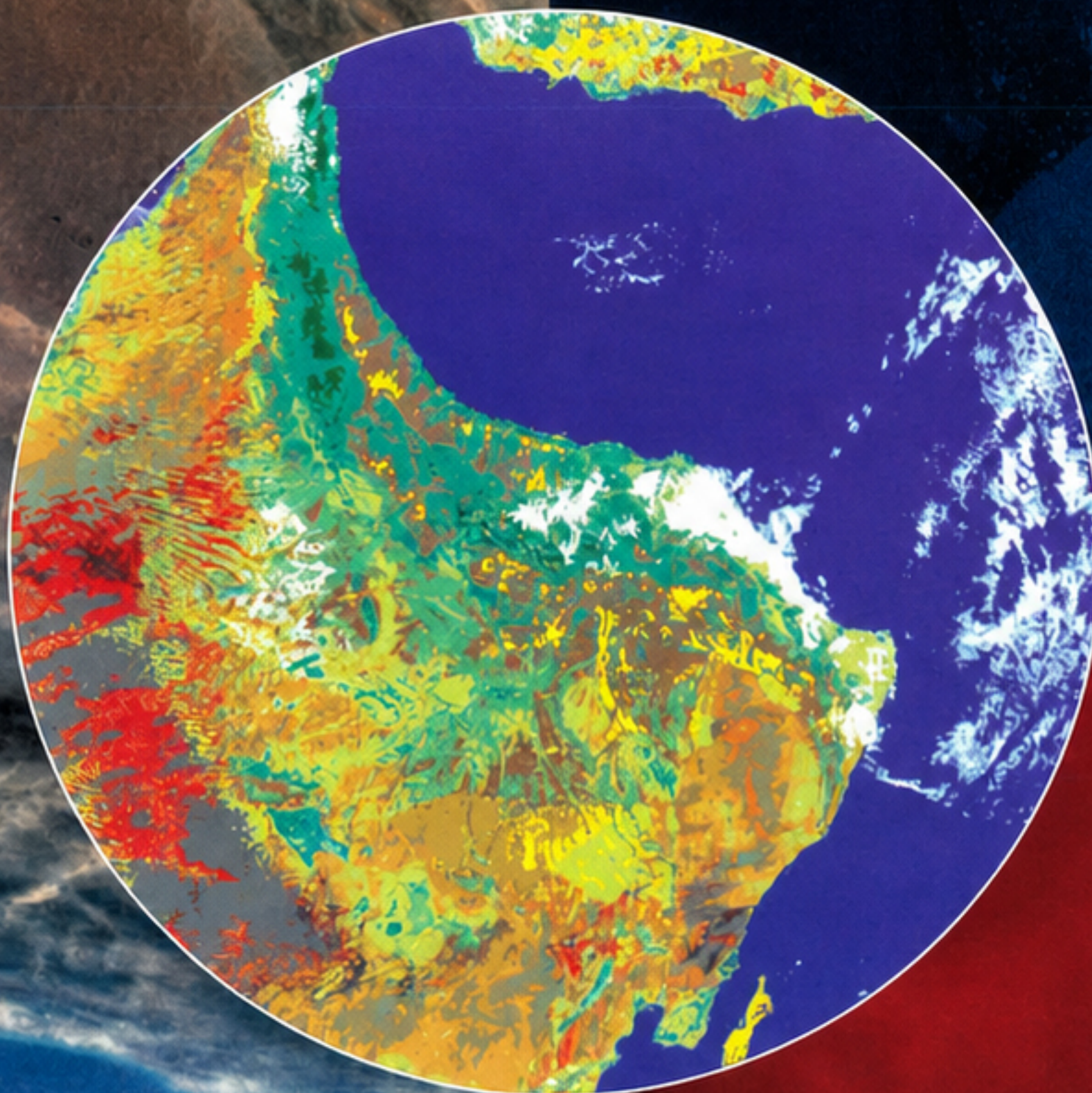




WEST IRAN, FRAGMENT  
FROM ZAGROS MOUNTAINS,  
VEGETATION APPEARS RED-  
DISH.  
LANDSAT MSS, 1975. RGB  
COLOUR COMBINATION OF  
BANDS 4, 2, 1.  
(SEE FIGURE III.6A)











The eight coastal States of the Region (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) have been aware for years of the necessity to co-ordinate a common action to protect the semi-enclosed sea surrounded by them.

This concern to protect the marine environment against pollution from various sources provided the bases for the initiative of the Governments of the Region to develop the Kuwait Action Plan, as indicated in the decision of the UNEP Governing Council. Upon the invitation of the Government of Kuwait, a Regional Conference was convened in Kuwait in 1978, which adopted the Kuwait Action Plan for the Protection and Development of the Marine Environment and the Coastal Areas, Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution and the Protocol concerning Regional Co-operation in Combating Pollution by oil and other Harmful Substances in Cases of Emergency.

In order to implement these legal instruments, the Regional Organisation for the Protection of the Marine Environment (ROPME) was established in July 1979. The Marine Emergency Mutual Aid Centre (MEMAC), situated in Bahrain, was established in 1982 in order to strengthen the capacities of the Contracting States and to facilitate co-operation among them in order to combat pollution by oil and other harmful substances in cases of marine. ROPME consists of three organs i.e. the Council, the Secretariat and the Judicial Commission. The Secretariat, headed by the Executive Secretary Dr. Abdul Rahman Al-Awadi runs the affairs of the organisation, and co-ordinates activities with UN and other international organisations.



The United Nations Environment Programme (UNEP) is the part of the UN responsible for the environmental issues. It was established in 1972 by the UN General Assembly following a recommendation from the United Nations Conference on the Human Environment (Stockholm, 1972). UNEP's uniqueness lies in its advocacy of environmental concerns within the international system. The Executive Director and Undersecretary of the United Nations, Dr. Klaus Topfer, has summarised his vision for UNEP as "having a strong environmental assessment, monitoring and early warning capacity. It is a vision of UNEP being fully capable of raising consciousness and awareness and educating people about actions that negatively affect the environment. It is a vision of UNEP that not only speaks strongly on behalf of the environment, but which goes well beyond speaking and is truly capable of catalysing action".

UNEP views assessment as a key part of its work and is involved in a large number of initiatives, on both global and regional levels, to assess the state of the environment, to identify areas of high risk and develop solutions. This book provides one such example of regional assessment work and emphasises the importance placed by UNEP on working with regional organisations to develop innovative methods of assessment, monitoring and protecting the global environment.





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